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16. ABSTRACT

This report discusses unit processes and combinations of unit processes that are capable of removing contaminants included in the National Interim Primary Drinking Water Regulations. Construction and operation and maintenance cost curves are presented for 99 unit processes that are considered to be especially applicable to contaminant removal. The report is divided into four volumes. Volume 1 is a summary volume. Volume 2 presents cost curves applicable to large water supply systems with treatment capacities between 1 and 200 mgd, as well as information on virus and asbestos removal. Volume 3 includes cost curves applicable to flows of 2,500 gpd to 1 mgd. And Volume 4 is a computer program user's manual for the curves included in the report. For each unit process included in this report, conceptual designs were formulated, and construction costs were then developed using the conceptual designs. The construction cost curves were checked for accuracy by a second consulting engineering firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. Operation and maintenance requirements were determined individually for three categories: Energy, maintenance material, and labor. Energy requirements for the building and the process are presented separately. Costs are in October 1978 dollars.

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ESTIMATING WATER TREATMENT COSTS

Volume 2. Cost Curves Applicable to 1 to 200 mgd Treatment Plants

by

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research - a most vital communications link between the researcher and the user community.

The cost of water treatment processes that may be used for the removal of contaminants included in the National Interim Primary Drinking Water Regulations is of interest to the U.S. Environmental Protection Agency, State and local agencies, and consulting engineers. Volume 2 presents construction and operation and maintenance cost curves for 72 unit processes that are especially applicable to water supply systems with treatment capacities between 1 and 200 mgd. These 72 processes were selected for their ability to remove (either individually or in combination) contaminants included in the National Interim Primary Drinking Water Regulations

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

This report is Volume 2 of a four-volume study that presents construction and operation and maintenance cost curves for 99 unit processes that are especially applicable (either individually or in combination) to the removal of contaminants listed in the National Interim Primary Drinking Water Regulations. This volume discusses 72 unit processes that are particularly suited to large water supply systems with treatment capacities between 1 and 200 mgd (3,785 and 757,000 m^3/d). Information is also included on enhanced virus and asbestos removal using modifications of standard unit processes.

Volume 1 summarizes the four volumes and discusses the cost-estimating approaches that were used to develop the cost curves and the treatment techniques applicable to contaminant removal. Volume 1 also presents a series of examples demonstrating the use of the cost curves. Volume 3 presents cost curves applicable to small water supply systems with capacities between 2,500 gpd and 1 mgd (9.46 and 3,785 m^3/d). Volume 4 is a computer program user's manual and contains a computer program that can be used to retrieve and update all cost data contained in the four volumes.

Conceptual designs were formulated for each unit process and from these, construction costs were then developed. The construction costs are presented in tabular form in terms of eight categories: Excavation and sitework, manufactured equipment, concrete, steel, labor, pipe and valves, electrical and instrumentation, and housing. The construction cost curves were checked for accuracy by a second consulting engineering firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. Construction costs are also shown plotted versus the most appropriate design parameter for the process, such as pounds per day for chemical feed systems and square feet of surface area for filters.

Operation and maintenance requirements were determined individually for three categories: Energy, maintenance material, and labor. Energy requirements for the building and the process were determined separately.

All costs are presented in terms of October 1978 dollars, and a discussion is included on cost updating. For construction cost, either of two methods may be used. One is the use of indices that are specific to each of the eight categories used in the original determination of construction cost. The second method is the use of an all-encompassing index such as the Engineering News Record Construction Cost Index. Operation and maintenance requirements may be readily updated or adjusted to local conditions, since labor requirements are expressed in hours per year, electrical requirements in kilowatt hours per year, diesel fuel in gallons per year, and natural gas in standard cubic feet per year.

This report was submitted in fulfillment of Contract No. 68-03-2516 by Culp/Wesner/Culp under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period November 1, 1976 to January 1, 1979, and work was completed as of July 2, 1979.

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ABBREVIATIONS AND SYMBOLS

ft	--	foot
ft^2	--	square foot
ft^3	--	cubic feet
G	--	velocity gradient - feet per second per foot
gal	--	gallon
gpd	--	gallons per day
gpd/ft^2	--	gallons per day per square foot
gpm	--	gallons per minute
hr	--	hours
kg	--	kilogram
kw-hr	--	kilowatt-hour
l	--	liter
lb	--	pound
lpd	--	liters per day
lpd/m^3	--	liters per day per cubic meter
lps	--	liters per second
m	--	meter
m^2	--	square meter
m^3	--	cubic meter
m^3/d	--	cubic meters per day
m^3/s	--	cubic meters per second
mg	--	million gallons
mg/l	--	milligrams per liter
mgd	--	million gallons per day
min	--	minutes
mph	--	miles per hour
psi	--	pounds per square inch
scf	--	standard cubic foot
tdh	--	total dynamic head
tu	--	turbidity unit
yd^3	--	cubic yards
yr	--	year

METRIC CONVERSIONS

English Unit	Multiplier	Metric Unit
cu ft	0.028	m^3
cu yd	0.75	m^3
ft	0.3048	m
gal	3.785	l
gal	0.003785	m^3
gpd	0.003785	m^3/d
gpd/ft^2	40.74	lpd/m^2
gpm	0.0631	l/s
lb	0.454	kg
mgd	3785	m^3/d
mgd	0.0438	m^3/sec
sq ft	0.0929	m^2

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SECTION 1

INTRODUCTION

SCOPE

This report is Volume 2 of a four-volume study that presents construction and operation and maintenance cost curves for 99 unit processes that are especially applicable (either individually or in combination) to the removal of contaminants listed in the National Interim Primary Drinking Water Regulations. This volume discusses 72 unit processes that are particularly suited to large water supply systems, 1 to 200 mgd (3,785 to 757,000 m^3/d). Information is also included on enhanced virus and asbestos removal using modifications of standard unit processes. The costs were developed to a high level of accuracy initially and were then checked by a second engineering consulting firm, Zurheide-Herrmann, Inc., using cost-estimating techniques similar to those used by general contractors in preparing their bids. The cost information for the 72 unit processes is presented in both graphic and tabular form for both construction and operation and maintenance. A description of the methodology used to derive the cost curves and to update them is presented in Volume 1 of the report.

BACKGROUND

The Safe Drinking Water Act, Public Law 93-523,[1] enacted on December 16, 1974, empowered the Administrator of the U.S. Environmental Protection Agency (EPA) to control the quality of the drinking water in public water systems by regulation and other means. The Act specified a three-stage mechanism for the establishment of comprehensive regulations for drinking water quality:

1. Promulgation of National Interim Primary Drinking Water Regulations.
2. A study to be conducted by the National Academy of Sciences (NAS) within 2 years of enactment on the human health effects of exposure to contaminants in drinking water.
3. Promulgation of Revised National Primary Drinking Water Regulations based on the NAS Report.

National Interim Primary Drinking Water Regulations were promulgated on December 24, 1975,[2] and July 9, 1976,[3] and they became effective on June 24, 1977. These Regulations were based on the Public Health Service Drinking Water Standards of 1962, as revised by the EPA Advisory Committee on the Revisions and Application of the Drinking Water Standards. They are intended to protect health to the maximum extent feasible using treatment methods that are generally available and take cost into consideration. The National Interim Primary Drinking Water Regulations contain maximum contaminant levels (MCL) and monitoring requirements for 10 inorganic chemicals, 6 organic pesticides, 2 categories of radionuclides, coliform organisms, and turbidity. An amendment to the National Interim Primary Drinking Water Regulations was proposed on February 9, 1978.[4] This amendment would establish regulations for total trihalomethanes and establish treatment technique requirements for the control of synthetic organic chemicals for community water systems serving populations of more than 75,000. Secondary Drinking Water Regulations were proposed by EPA on March 31, 1977.[5] A list of the contaminants presently included in the National Interim Primary Drinking Water Standards, along with the MCL for each contaminant, is presented in Volume 1 of this report.

The Interim Regulations are devoted to contaminants affecting the health of consumers, whereas the secondary regulations include those contaminants that deal primarily with aesthetic qualities of drinking water. The Interim Primary Regulations are applicable to all public water systems and are enforceable by EPA or the States that have accepted primacy. Secondary regulations are not Federally enforceable and are intended as guidelines for the States.

The National Academy of Sciences (NAS) Summary Report was delivered to Congress on May 26, 1977, and the full report, Drinking Water and Health[6] was delivered on June 20, 1977. The NAS Summary Report was also published in the Federal Register on Monday, July 11, 1977. Based on the completed NAS report and the findings of the Administrator, EPA will publish:

1. Recommended MCL's (health goals) for substances in drinking water that may have adverse effects on humans. These recommended levels will be selected so that no known or anticipated adverse effects would occur, allowing an adequate margin of safety. A list of contaminants that may have adverse effects but that cannot be accurately measured in water will also be published.
2. Revised National Primary Drinking Water Regulations. These will specify MCL's or require the use of treatment techniques. MCL's will be as close to the recommended levels for each contaminant as feasible. Required treatment techniques for those substances that cannot be measured will reduce their concentrations to a level that is as close to the recommended level as feasible. Feasibility is defined in the Act as use of the best technology, treatment techniques, and other means that the Administrator finds are generally available (taking costs into consideration).

On February 9, 1978, the EPA proposed to amend the National Interim Primary Drinking Water Regulations by adding regulations for organic chemical contaminants in drinking water. The proposed amendment[4] consisted of two parts:

1. An MCL of 0.10 mg/l (100 parts per billion) for total trihalomethanes (TTHM), including chloroform.

2. A treatment technique requiring the use of granular activated carbon for the control of synthetic organic chemicals. Three criteria that the granular activated carbon must achieve are: (1) an effluent limitation of 0.5 μg/l for low molecular weight halogenated organics (excluding TTHM), (2) a limit of 0.5 mg/l for effluent total organic carbon concentration when fresh activated carbon is used, and (3) the removal of at least 50 percent of influent total organic carbon when fresh activated carbon is used.

These proposed amendments are initially applicable to community water systems serving populations of more than 75,000.

PURPOSE AND OBJECTIVES

The purpose of Volume 2 is to present the cost of treatment processes and techniques that are applicable to the treatment of flows between 1 and 200 mgd. Construction costs were developed and are presented in terms of eight individual components; operation and maintenance costs were developed and are presented in terms of four components. This approach was used to facilitate both the original cost derivation, as well as to facilitate the updating of costs.

The unit processes presented in this volume, listed in order of their presentation are:

- Chemical Feed Processes
  - Chlorine Storage and Feed Systems
  - Chlorine Dioxide Generating and Feed Systems
  - Ozone Generation Systems and Contact Chambers
  - On-Site Hypochlorite Generation Systems
  - Alum Feed Systems
  - Polymer Feed Systems
  - Lime Feed Systems
  - Potassium Permanganate Feed Systems
  - Sulfuric Acid Feed Systems
  - Sodium Hydroxide Feed Systems
  - Ferrous Sulfate Feed Systems
  - Ferric Sulfate Feed Systems
  - Ammonia Feed Facilities
  - Powdered Activated Carbon Feed Systems
- Flocculation, Clarification, and Filtration Processes
  - Rapid Mix
  - Flocculation
  - Circular Clarifiers
  - Rectangular Clarifiers
  - Upflow Solids Contact Clarifiers
  - Tube Settling Modules
  - Gravity Filtration Structures
  - Filtration Media
  - Backwash Pumping Facilities
  - Hydraulic Surface Wash Systems

Air-Water Backwash Facilities
Wash Water Surge Basins
Modification of Rapid Sand Filters to High-Rate Filters
Continuous Automatic Backwash Filters
Recarbonation Basins
Recarbonation - Liquid CO_2 as CO_2 Source
Recarbonation - Submerged Burners as CO_2 Source
Recarbonation - Stack Gas as CO_2 Source
Multiple Hearth Recalcination
Contact Basins
Pressure Diatomite Filters
Vacuum Diatomite Filters
Pressure Filtration Plants
In-Plant Pumping
Wash Water Storage Tanks

Reverse Osmosis and Ion Exchange Processes

Reverse Osmosis
Ion Exchange - Softening
Pressure Ion Exchange - Nitrate Removal
Activated Alumina for Fluoride Removal

Activated Carbon Processes

Gravity Carbon Contactors - Concrete Construction
Gravity Carbon Contactors - Steel Construction
Pressure Carbon Contactors
Conversion of Sand Filter to Carbon Contactor
Granular Activated Carbon
Capping Sand Filters with Anthracite
Off-Site Regional Carbon Regeneration - Handling and Transportation
Multiple Hearth Granular Carbon Regeneration
Infrared Carbon Regeneration Furnace
Granular Carbon Regeneration - Fluid Bed Process
Powdered Carbon Regeneration - Fluidized Bed Process
Powdered Carbon Regeneration - Atomized Suspension Process

Sludge Pumping, Dewatering, and Disposal Costs

Chemical Sludge Pumping - Unthickened Sludge
Chemical Sludge Pumping - Thickened Sludge
Gravity Sludge Thickeners
Vacuum Filters
Sludge Dewatering Lagoons
Filter Press
Decanter Centrifuges
Basket Centrifuges
Sand Drying Beds
Belt Filter Press
Sludge Disposal to Sanitary Sewers
Sludge Hauling to Landfill

Miscellaneous Processes

Raw Water Pumping Facilities
Finished Water Pumping Facilities
Clearwell Storage
Aeration
Administration, Laboratory, and Maintenance Building

SECTION 2

COST CURVES

CONSTRUCTION COST CURVES

The construction cost curves were developed using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. When unit cost takeoffs were used to determine costs from actual and conceptual designs, estimating techniques from Richardson Engineering Services Process Plant Construction Estimating Standards,[7] Mean's Building Construction Cost Data,[8] and the Dodge Guide for Estimating Public Works Construction Costs[9] were often utilized. The cost curves that were developed were then checked and verified by a second engineering consulting firm, Zurheide-Herrmann, Inc., using an approach similar to that which a general contractor would utilize in determining his construction bid. Every attempt has been made to present the conceptual designs and assumption that were incorporated into the curves. Adjustment of the curves may be necessary to reflect site-specific conditions, geographic or local conditions, or the need for standby power. The curves should be particularly useful for estimating the relative economics of alternative treatment systems and for the preliminary evaluation of general cost level to be expected for a proposed project. The curves contained in this report are based on October 1978 costs.

The construction cost was developed by determining and then aggregating the cost of eight principal components which were utilized primarily to facilitate accurate cost updating (discussed in a subsequent section of this chapter). The division will also be helpful where costs are being adjusted for site-specific, geographic, and other special conditions. The eight categories include the following general items:

Excavation and Sitework. This category includes work related only to the applicable process and does not include any general sitework such as sidewalks, roads, driveways, or landscaping.

Manufactured Equipment. This category includes estimated purchase cost of pumps, drives, process equipment, specific purpose controls, and other items that are factory made and sold with equipment.

Concrete. This category includes the delivered cost of ready-mix concrete and concrete-forming materials.

Steel. This category includes reinforcing steel for concrete and miscellaneous steel not included within the manufactured equipment category.

Labor. The labor associated with installing manufactured equipment and piping and valves, constructing concrete forms, and placing concrete and reinforcing steel are included in this category.

Pipe and Valves. Cast iron pipe, steel pipe, valves, and fittings have been combined into a single category. The purchase price of pipe, valves, fittings, and associated support devices are included in this category.

Electrical Equipment and Instrumentation. The cost of process electrical equipment, wiring, and general instrumentation associated with the process equipment is included in this category.

Housing. In lieu of segregating building costs into several components, this category represents all material and labor costs associated with the building, including heating, ventilating, air conditioning, lighting, normal convenience outlets, and the slab and foundation.

The subtotal of the costs of these eight categories includes the cost of material and equipment purchase and installation, and the subcontractor's overhead and profit. To this subtotal, a 15-percent allowance has been added to cover miscellaneous items not included in the cost takeoff, as well as contingency items. Experience at many water treatment facilities has indicated that this 15-percent allowance is reasonable. Although blanket application of this 15-percent allowance may result in some minor inequities between processes, these are generally balanced out, during the combination of costs for individual processes into a treatment system.

The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. For example, construction costs for gravity filters are plotted versus square feet of filter surface area, whereas ozone generation system costs are presented versus pounds per day of feed capacity. Use of such key design parameters allows the curves to be utilized with greater flexibility than if cost information were plotted versus flow.

The construction costs shown in the curves do not equal the final capital cost for the unit process. The construction cost curves do not include costs for special sitework, general contractor overhead and profit, engineering, land, or legal, fiscal, and administrative and interest during construction. These cost items are all more directly related to the total cost of a project than to the cost of the individual unit processes. They therefore are most appropriately added following summation of the cost of the individual unit processes, if more than one unit process is required. An example calculation for a 40-mgd conventional treatment plant is presented in a subsequent section of this volume, and a number of other examples are given in Volume 1 of this report. These examples illustrate the recommended method for the addition of these costs to the construction cost.

OPERATION AND MAINTENANCE COST CURVES

Operation and maintenance curves were developed for: (1) energy requirements, (2) maintenance material requirements, (3) labor requirements, and (4) total operation and maintenance cost. The energy categories included are: process energy, building energy, diesel fuel, and natural gas. The operation and maintenance requirements were determined from operating data at existing plants, at least to the extent possible. Where such information was not available, assumptions were made based on the experience of both the author and the equipment manufacturer, and such assumptions are stated in the description of the cost curve.

Electrical energy requirements were developed for both process energy and building-related energy, and they are presented in terms of kilowatt-hours per year. This approach was used to allow adjustment for geographical influence on building-related energy. For example, though lighting requirements average about 17.5 kw-hr/ft^2 per year throughout the United States, heating, cooling, and ventilating requirements vary from a low of about 8 kw-hr/ft^2 per year in Miami, Florida, to a high of about 202 kw-hr/ft^2 per year in Minneapolis, Minnesota. The building energy requirements presented for each process are in terms of kilowatt-hours per year, and were calculated using an average building-related demand of 102.6 kw-hr/ft^2 per year. This is an average for the 21 cities included in the Engineering News Record (ENR) Index. An explanation of the derivation of this figure is included in Volume 1, Appendix B, of this report. The computer program developed as a portion of this project will allow use of other building-related energy demands than 102.6 kw-hr/ft^2 per year. Process electrical energy is also included in the electrical energy curve and was calculated using manufacturers data for required components. Where required, separate energy curves for natural gas and diesel fuel are also presented. When using the curves to determine energy requirements, the design flow or parameter should be utilized to determine building energy, and the operating flow or parameter should be used to determine process energy, diesel fuel, and natural gas.

Maintenance material costs include the cost of periodic replacement of component parts necessary to keep the process operable and functioning. Examples of maintenance material items included are valves, motors, instrumentation, and other process items of similar nature. The maintenance material requirements do not include the cost of chemicals required for process operation. Chemical costs must be added separately, as will be shown in the subsequent example. The operating parameter should be used to determine maintenance material requirements.

The labor requirement curve includes both operation and maintenance labor, and it is presented in terms of hours per year. The operating parameter should be used to determine the labor requirement.

The total operation and maintenance cost curve is a composite of the energy, maintenance material, and labor curves. To determine annual energy costs, unit costs of \$0.03/kw-hr of electricity, \$0.0013/scf of natural gas, and \$0.45/gal of diesel fuel were utilized. The labor requirements were converted to an annual cost using an hourly labor rate of \$10.00/hr, which includes salary and fringe benefits. The computer program that was developed as a portion of this project and that is presented in Volume 4 of this report will allow utilization of other unit costs for energy and labor.

UPDATING COSTS TO TIME OF CONSTRUCTION

Continued usefulness of the curves developed as a portion of this project depends on the ability of the curves to be updated to reflect inflationary increases in the prices of the various components. Most engineers and planners are accustomed to updating costs using one all-encompassing index, which is developed by tracking the cost of specific items and then proportioning the costs according to a predetermined ratio. The key advantage of a single index is the simplicity with which it can be applied. Although use of a single index is an uncomplicated approach, there is much evidence to indicate that these time-honored indices are not understood by many users and/or are inadequate for application to water works construction.

The most frequently utilized single indices in the construction industry are the ENR Construction Cost Index (CCI) and Building Cost Index (BCI). These ENR indices were started in 1921 and were intended for general construction cost monitoring. The CCI consists of 200 hr of common labor, 2,500 lb of structural steel shapes, 1.128 tons of Portland cement, and 1,008 board feet of 2 x 4 lumber. The BCI consists of 68.38 hr of skilled labor plus the same materials included in the CCI. The large amount of labor included in the CCI was appropriate before World War II; however, on most contemporary construction, the index labor component is far in excess of actual labor used.

To update the construction cost using the CCI, which was 265.38 in October 1978, the following formula may be utilized:

$$\text{Updated Cost} = \text{Total Construction Cost from Curve } \left(\frac{\text{Current CCI}}{265.38}\right)$$

This approach may also be utilized in the computer program that was developed for this report.

Although key advantages of the ENR indices include their availability, their simplicity, and their geographical specificity, many engineers and planners believe that these indices are not applicable to water treatment plant construction. The rationale for this belief is that the indices do not include mechanical equipment or pipe and valves that are normally associated with such construction, and the proportional mix of materials and labor is not specific to water treatment plant construction.

An approach that may be utilized to overcome the shortcomings of the ENR indices relative to water works construction is to apply specific indices to the major cost components of the construction cost curves. This approach allows the curve to be updated using indices specific to each category and weighted according to the dollar significance of the category. For the eight major categories of construction cost, the following Bureau of Labor Statistics (BLS)[10] and ENR indices were utilized as a basis for the cost curves included in this report.

Cost Component		October 1978 Value of Index
Excavation and Sitework	ENR Wage Index (Skilled Labor)	247
Manufactured Equipment	BLS General Purpose Machinery and Equipment - Code 114	221.3
Concrete	BLS Concrete Ingredients - Code 132	221.1
Steel	BLS Steel Mill Products - Code 1013	262.1
Labor	ENR Wage Index (Skilled Labor)	247
Pipe and Valves	BLS Valves and Fittings - Code 114901	236.4
Electrical Equipment and Instrumentation	BLS Electrical Machinery and Equipment - Code 117	167.5
Housing	ENR Building Cost Index	254.76

The principal disadvantages of this approach are the lack of geographical specificity of the BLS indices and the use of seven indices rather than a single index.

To update the construction costs using the above two ENR and six BLS indices, the construction cost from the construction cost curve must first be broken down into the eight component categories. One acceptable method of accomplishing this breakdown is to utilize all the detailed cost estimates included in the construction cost table to determine the average percent of the subtotal construction cost for each of the eight (or fewer) construction cost components. The appropriate index for each component can then be used to update the component cost. For example, in the construction cost table for chlorine storage and feed systems, cylinder storage, the sum of the manufactured equipment costs for the six designs is $327,110, and the subtotal of construction costs for these six designs is $811,580. The ratio of these two costs is 0.4031, meaning that on the average, manufactured equipment is 40.31 percent of the subtotal construction cost. Therefore, if the construction cost curve gives a construction cost of $150,000, and the BLS General Purpose Machinery and Equipment Index is 250, the manufactured equipment cost would be:

$$\text{Manufactured Equipment Cost} = 0.4031\ (\$150{,}000)\ \left(\frac{250}{221.3}\right) = \$68{,}310$$

When this approach is used with each of the components of construction cost, the updated sum gives the subtotal of construction cost, and the updated total construction cost is obtained by adding 15 percent to this updated subtotal cost. Either this approach or the previously described approach using the CCI may be used with the computer program presented in Volume 4 of this report.

Updating of total operation and maintenance costs may be accomplished by updating the three individual components: energy, labor, and maintenance material. Energy and labor are updated by applying the current unit costs to the kilowatt hour and labor requirements obtained from the energy and labor curves. Maintenance material costs, which are presented in terms of dollars per year, can be updated using the Producer Price Index for Finished Goods.[10] The maintenance material costs in this report are based on an October 1978 Producer Price Index for Finished Goods of 199.7

FIRMS THAT SUPPLIED COST AND TECHNICAL INFORMATION

During the development of both construction and operation and maintenance cost curves, a large number of equipment manufacturers and other firms were contacted to determine cost and technical information. The help provided by those firms that did respond is sincerely appreciated, for the information furnished was instrumental in assuring a high level of accuracy for the curves. The manufacturers and other firms that provided input to this study were:

Acrison, Inc.
Advance Chlorination Equipment
Aqua-Aerobic Systems, Inc.
Aquafine Corporation
BIF, a Division of General Signal Corporation
Bird Centrifuge
Capital Control Company
Ralph B. Carter Company
Chemical Separations Corporation
Chicago Bridge and Iron Company
Chicago, Rock Island and Pacific Railroad Company
Chromalloy, L.A. Water Treatment Division
Clarkson Industries, Inc., Hoffman Air & Filtration Division
Colt Industries, Inc., Fairbanks Morse Pump Division
Continental Water Conditioning
Copeland Systems
Crane Company, Cochrane Environmental Systems
Curtiss-Wright Corporation
DeLaval Turbine, Inc.
Dorr-Oliver, Inc.
Dravo Corporation
E.I. Dupont De Nemours & Company, Inc.
The Duriron Company, Inc., Filtration Systems Division
The Eimco Corporation
Electrode Corporation, A Subsidiary of Diamond Shamrock Corporation
Englehard Industries

Envirex, Inc., - A Rexnord Company
Environmental Conditioners
Environmental Elements Corp., Subsidiary of Koppers Co., Inc.
Envirotech Corporation
Fischer and Porter Company
FMC Corporation
General Filter Company
Infilco Degremont, Inc.
Ionics, Inc.
Johns-Manville
Kaiser Chemicals
Keystone Engineering
Komline-Sanderson Engineering Corporation
Merck & Co., Inc., Calgon Company
Mixing Equipment Company, Inc.
Morton-Norwick Products, Inc., Morton Salt Company
Muscatine Sand and Gravel
Nash Engineering Company
Neptune Micro Floc, Inc.
Nichols Engineering & Research Corp., Neptune International Corp.
Northern Gravel Company
Ozark-Mahoning Company
Pacific Engineering & Production Company of Nevada
PACO
R.H. Palmer Coal Company
Passavant Corporation
PCI Ozne Corp., A Subsidiary of Pollution Control Industries, Inc.
Peabody Welles, Inc.
Peerless Pump
Pennwalt Corporation
The Permutit Company, Inc., Division of Sybron Corporation
Reading Anthracite Company
Robbins & Meyers, Inc., Moyno Pump Division
Rohm and Haas Company, Fluid Process Chemicals Department
Shirco, Inc.
D.R. Sperry & Company
Sybron Corporation, R.B. Leopold Co. Division
TOMOCO2 Equipment Company
Union Carbide Corporation - Linde Division
Universal Oil Products Company, Fluid Systems Division
U.S. Filter Co., Inc., Califilco Division
Westvaco Corporation, Chemical Division
Western States Machine Company
Worthington Pump, Inc.
Zimpro, Inc.

CHLORINE STORAGE AND FEED SYSTEMS

Construction Cost

The costs for chlorine feed facilities have been based on use of 150 lb cylinders for feed rates up to 100 lb/day and ton cylinders for feed rates up to 2,000 lb/day. For rates of 2,000 lb/day and greater, three options were considered: (1) ton cylinders, (2) on-site storage with bulk rail delivery, and (3) direct feed from a rail car.

Cylinder Storage--

The maximum chlorinator capacity utilized was 8,000 lb/day, and one standby chlorinator was included for each installation. The costs include cylinder scales for all installations, and evaporators are included for delivery rates of 2,000 lb/day and greater. Residual analyzers with flow-proportioning controls were included for flow rates greater than 1,000 lb/day. Costs were also included for injector pumps capable of delivering sufficient water at 25 psi to allow production of a 3,500-mg/l, high-strength solution. Housing cost includes both the chlorinator room and the cylinder storage room. All cylinders were assumed to be stored indoors, with 30 days of storage provided. For feed rates greater than 100 lb/day, electrically operated, monorail trolley hoists were included.

On-Site Storage Tank with Rail Delivery--

Use of an on-site storage tank would eliminate the housing requirement for cylinder storage, the monorail and hoist, the cylinder scale, cylinder trunnions, and the cylinder manifold piping. However, additive costs are incurred for the tank and its supports, a tank sun shield, load cells for the tank, a railhead connection and associated track, unloading platform, an air padding system, expansion tanks, and miscellaneous gauges, switches, and piping. All considerations relating to the chlorinators, evaporators, and other feed equipment remain the same as for the ton cylinder curve. The amount of chlorine storage provided with the on-site tank is 30 days.

The rail siding costs include the cost of a turnout from the main line, 500 ft of on-site track, and the unloading platform. Piping costs would be strongly influenced by the location of the storage tank relative to the chlorinators. Normally the storage tank is located near the plant boundary. Valving is more complex than with ton cylinders, mainly because of the unloading system, the use of duplicate heads for gas or liquid feed, and the air padding system.

This curve may be adapted to bulk truck delivery by removing the cost of the rail siding.

Direct Feed from Rail Car--

Chlorine may be fed directly from the rail car to the evaporator, eliminating the requirement for an on-site storage tank. Ownership of the rail car may be by the utility or the chlorine manufacturer. In the latter case, a high cost per ton of chlorine must be paid to account for amortization and maintenance costs of the car. Chlorinator, evaporator, and other feed equipment costs are the same as for feed from ton cylinders. Rail siding costs are the same as for on-site storage with rail delivery.

Estimated construction costs are shown in Tables 1, 2, and 3 for feed systems between 10 and 10,000 lb/day, and the costs are shown graphically in Figure 1. As may be seen, construction costs for cylinder storage become greater than costs for on-site storage when the feed capacity approaches the range of 2,000 to 4,000 lb/day. It should also be noted that the cost of the chlorine itself is also less when it is purchased in bulk rather than in ton cylinders.

Operation and Maintenance Cost

Power requirements include heating, lighting, and ventilation of the chlorination building and the cylinder storage area, the electrical hoist when ton cylinders are used, evaporators when feed is 2,000 lb/day or greater, and the injector pump for the high-strength chlorine solution. This pump was sized to deliver sufficient flow for a maximum chlorine concentration of 3,500 mg/l in the high-strength solution. Where on-site storage tanks were utilized, the electrical hoist power requirements are eliminated, and heating, ventilating, and lighting power are significantly reduced as a result of elimination of indoor storage facilities.

Maintenance material requirements were based upon experience at operating plants and are essentially the same for use of cylinders, on-site storage, or rail-car storage and feed. Cost of chlorine is not included in the maintenance material estimates.

Labor requirements for cylinders were based on loading and unloading cylinders from a delivery truck, time to connect and disconnect cylinders from the chlorine headers, and the time for routine daily checking of the cylinders. For on-site tank storage, labor consists of time to unload a bulk delivery truck or rail tanker. The rail car storage concept requires labor only to move the rail car into place and to connect and disconnect the cars from the feed system. Common to all installations would be the time required for daily checking and periodic maintenance of the chlorine handling system.

Figures 2 and 3 present operation and maintenance curves for chlorine feed systems using cylinder storage. For feed rates greater than 2,000 lb/day and use of an on-site storage tank with rail delivery or the rail-car storage and feed, operation and maintenance requirements are shown in Figure 4 and 5. Table 4 presents a summary of operation and maintenance requirements for all three storage concepts.

CHLORINE DIOXIDE GENERATING AND FEED SYSTEMS

Construction Cost

Chlorine dioxide is most commonly generated by mixing a high-strength chlorine solution with a high-strength sodium chlorite solution. Mixing takes place in a PVC chamber filled with porcelain Raschig Rings, the chamber referred to as the chlorine dioxide generator. Chlorine dioxide may also be generated by acidifying solutions of sodium chlorite and sodium hypochlorite with sulfuric acid. This method is only applicable in very small installations with little operator time available, and it is not included in this cost curve.

Table 1

Construction Cost

Chlorine Storage and Feed Systems - Cylinder Storage

Cost Category	Chlorine Feed Capacity - lb/day					
	10	500	1,000	2,000	5,000	10,000
Manufactured Equipment	$ 6,760	$21,630	$41,630	$65,950	$76,780	$114,360
Labor	820	2,610	5,030	7,960	9,270	13,810
Pipe and Valves	540	1,710	3,300	5,230	6,080	9,060
Electrical and Instrumentation	770	2,450	4,710	7,460	8,690	12,940
Housing	2,430	18,360	27,760	46,550	100,440	186,490
SUBTOTAL	11,320	46,760	82,430	133,150	201,260	336,660
Miscellaneous and Contingency	1,700	7,010	12,360	19,970	30,190	50,500
TOTAL	13,020	53,770	94,790	153,120	231,450	387,160

Table 2

Construction Cost for Chlorine Storage and Feed Systems - On-Site Storage Tank with Rail Delivery

Cost Category	Chlorine Feed Capacity (lb/day) 2,000	5,000	10,000
Manufactured Equipment			
Equipment	$85,950	$103,780	$150,360
Rail Siding	48,410	48,410	48,410
Steel	2,400	3,800	6,200
Labor	11,560	15,470	23,810
Pipe and Valves	5,230	6,080	9,060
Electrical and Instrumentation	7,460	8,690	12,940
Housing	2,770	2,770	4,050
SUBTOTAL	163,780	189,000	254,830
Miscellaneous and Contingency	24,570	28,350	38,220
TOTAL	188,350	217,350	293,050

Table 3

Construction Cost for Chlorine Storage and

Feed Systems - Direct Feed from Rail Car

Cost Category	Chlorine Feed Capacity (lb/day)		
	2,000	5,000	10,000
Manufactured Equipment			
Equipment	$ 65,950	$76,780	$114,360
Rail Siding	48,410	48,410	48,410
Labor	7,960	9,270	13,810
Pipe and Valves	5,230	6,080	9,060
Electrical and Instrumentation	7,460	8,690	12,940
Housing	2,770	2,700	4,050
SUBTOTAL	137,780	151,930	202,630
Miscellaneous and Contingency	20,670	22,790	30,390
TOTAL	158,450	174,720	233,020

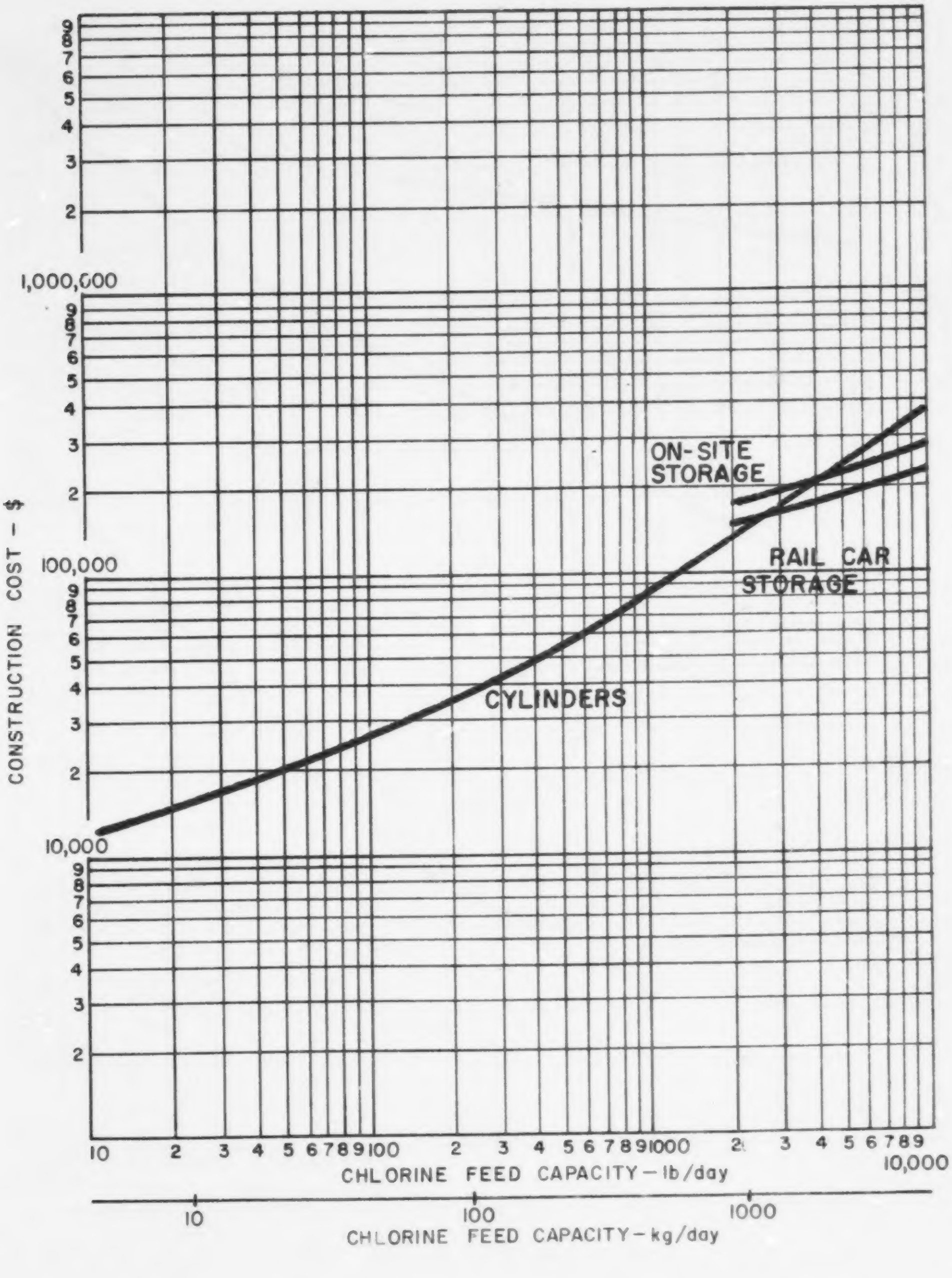


Figure 1. Construction cost for chlorine storage and feed systems.

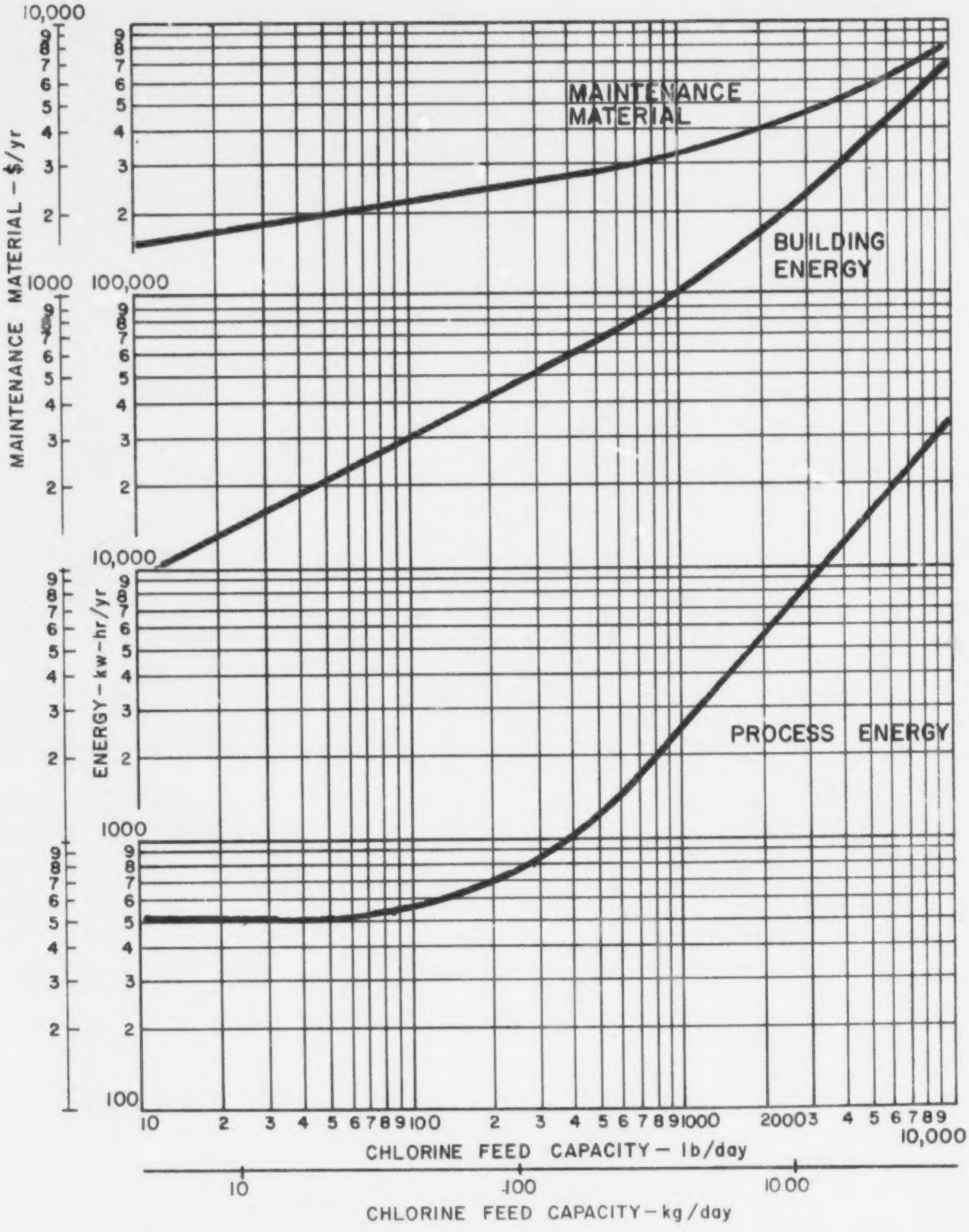


Figure 2. Operation and maintenance requirements for chlorine storage and feed systems, cylinder storage - building energy, process energy, and maintenance material.

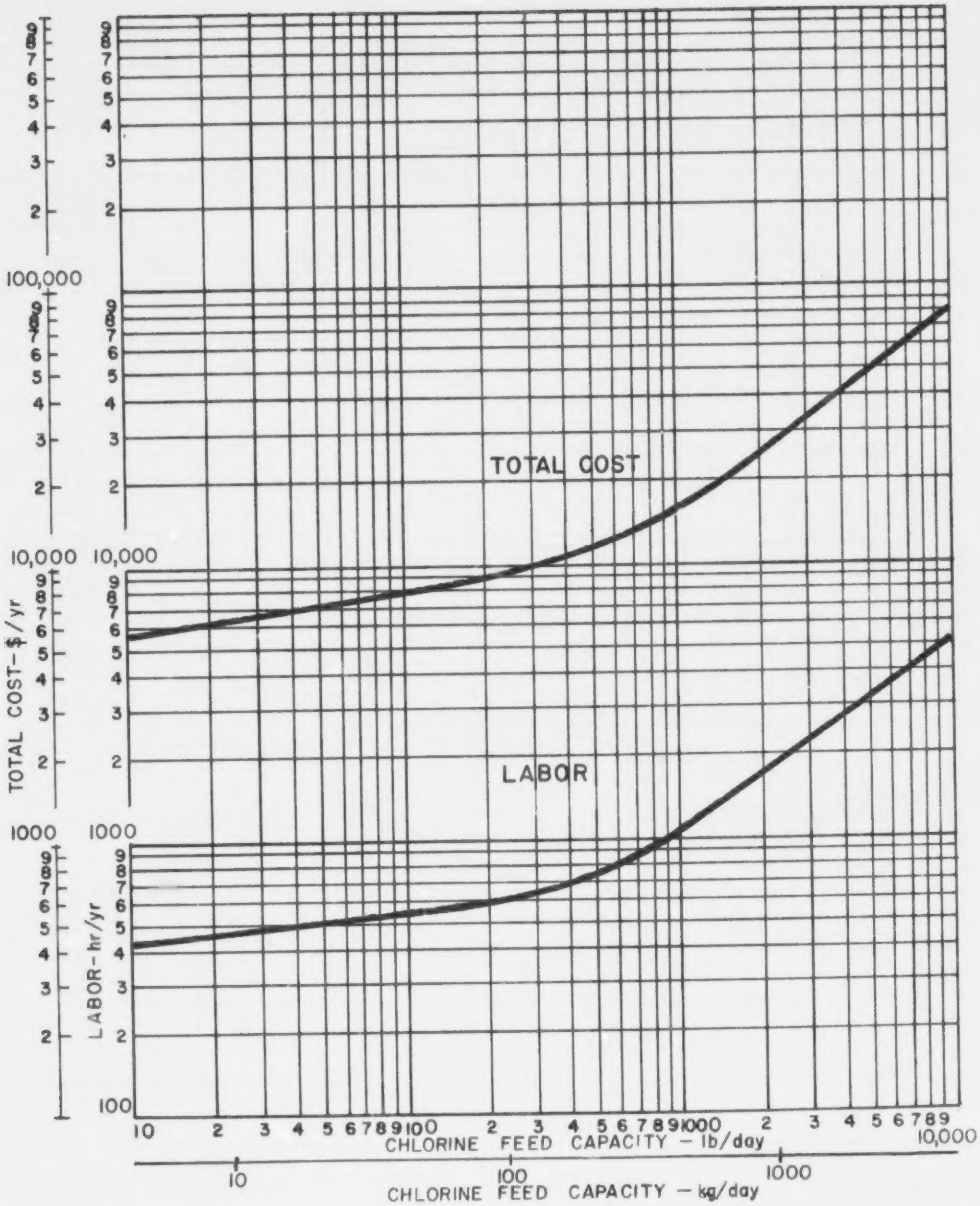


Figure 3. Operation and maintenance requirements for chlorine storage and feed systems, cylinder storage - labor and total cost.

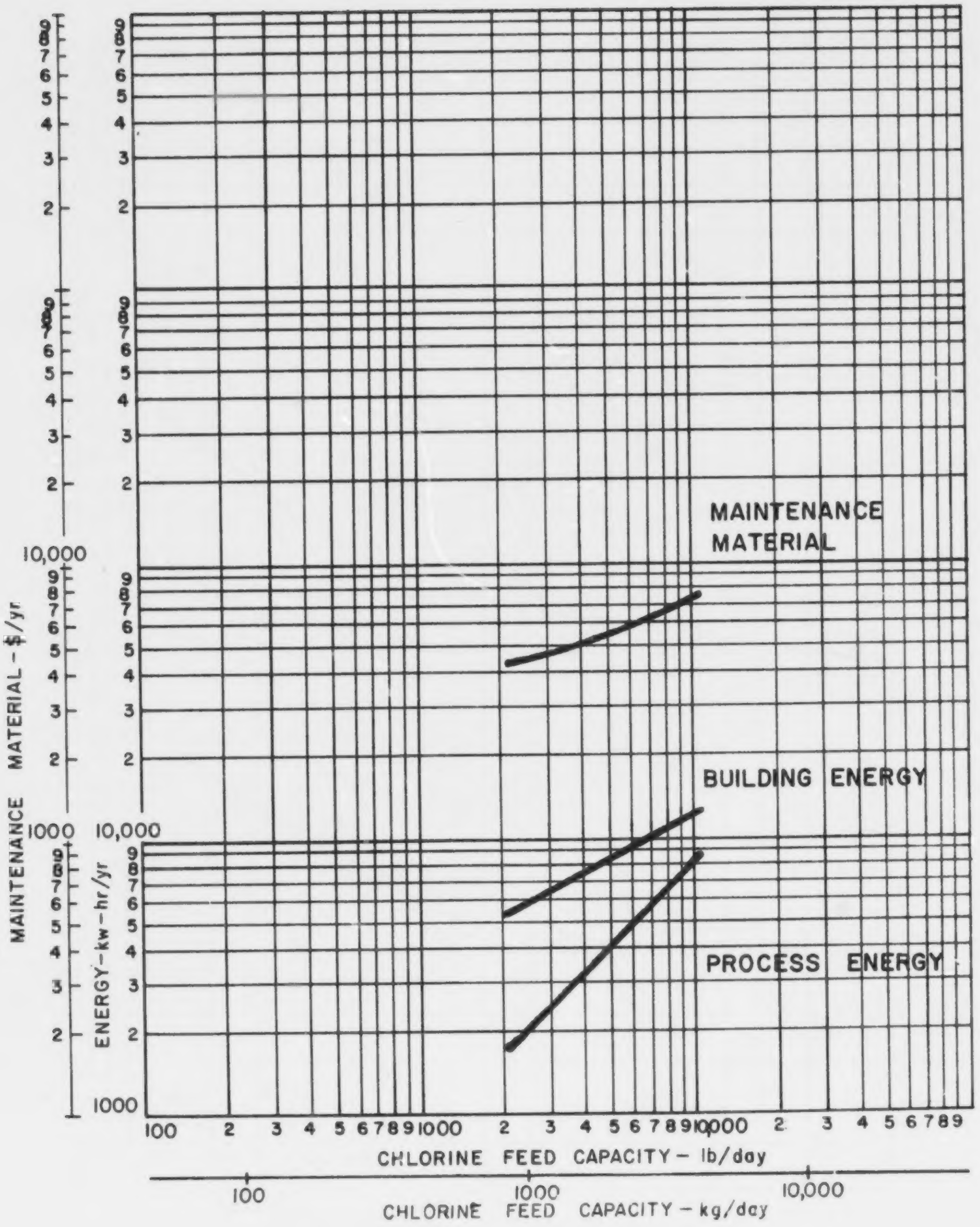


Figure 4. Operation and maintenance requirements for chlorine storage and feed systems, on-site storage tank and rail-car feed - building energy, process energy and maintenance material.

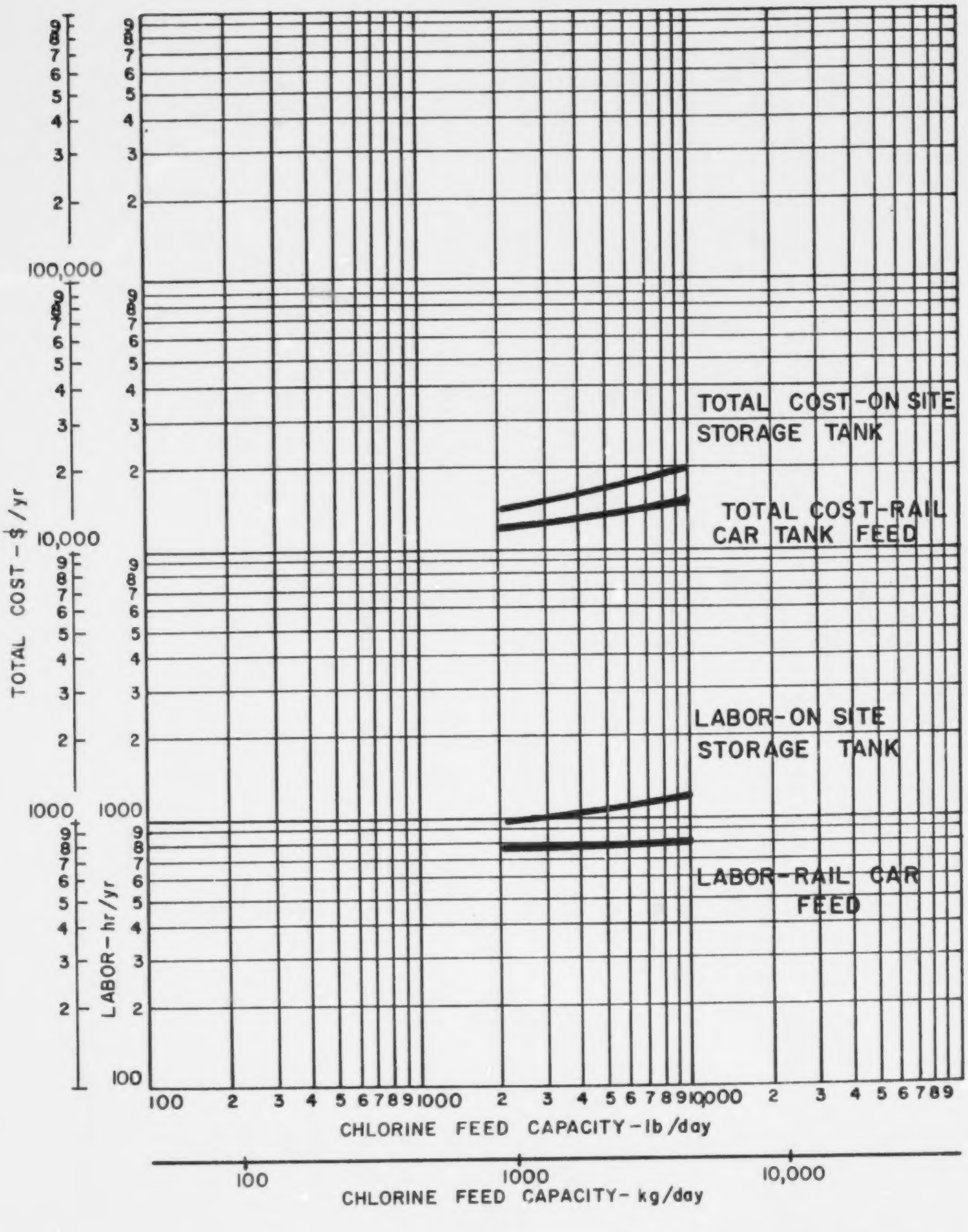


Figure 5. Operation and maintenance requirements for chlorine storage and feed systems, on-site storage tank and rail-car feed - labor and total cost.

Table 4

Operation and Maintenance Summary for Chlorine Storage and Feed Systems

Feed Rate (lb/day)	Energy kw-hr/yr			Maintenance Material $/yr	Labor hr/yr	Total Cost* $/yr
	Building	Process	Total			
Cylinder Storage:						
10	9,230	570	9,800	1,530	437	6,190
500	69,770	1,120	70,890	3,060	663	11,820
1,000	105,490	2,230	107,720	3,530	1,267	19,430
2,000	176,890	6,210	183,100	4,700	2,043	30,620
5,000	381,670	15,530	397,200	5,880	3,140	49,200
10,000	708,660	30,990	739,650	8,230	5,443	84,850
On-Site Storage, Rail Delivery:						
2,000	5,130	1,740	6,870	4,700	926	14,170
5,000	10,260	4,340	14,600	5,880	1,100	17,320
10,000	10,260	8,690	18,950	8,230	1,144	20,240
Direct Feed from Rail Car:						
2,000	5,130	1,740	6,870	4,700	754	12,450
5,000	10,260	4,340	14,600	5,880	790	14,220
10,000	10,260	8,690	18,950	8,230	796	16,760

*Calculated using $0.03/kw-hr and $10.00/hr of labor

In theory, 1.34 lb of pure sodium chlorite and 0.5 lb of chlorine react to give 1 lb of chlorine dioxide. However, since sodium chlorite is normally purchased with a purity of 80 percent, 1.68 lb of sodium chlorite are required per lb of chlorine dioxide generated. Chlorine is normally used at a 1:1 ratio with sodium chlorite to insure completion of the reaction and to lower the pH to 4. The cost curves have been developed using 1.68 lb of chlorine and 1.68 lb of sodium chlorite per lb of chlorine dioxide generated.

Costs have been based on the addition of costs for a sodium chlorite mixing and metering system, plus a chlorine dioxide generator, to the appropriate-sized chlorine feed system. The sodium chlorite system consists of a polythelene day tank, a mixer for the day tank, and a dual head metering pump. The chlorine dioxide generator is a PVC tube filled with porcelain Raschig Rings or other turbulence-producing media, and it is sized for a detention time of about 0.2 min.

Estimated construction costs are shown in Table 5 and Figure 6.

Operation and Maintenance Cost

Electrical requirements include power for the gaseous chlorination system, the sodium chlorite mixing and metering system, and building heating, lighting, and ventilation.

Maintenance material requirements are based on experience with gaseous chlorine systems and liquid metering systems. Chemical costs for sodium chlorite and chlorine are not included.

Labor requirements consist of labor for gaseous chlorination systems, plus the labor required to mix the sodium chlorite solution, to adjust its feed rate, and to maintain the mixing and metering equipment.

Figures 7 and 8 present operation and maintenance curves for chlorine dioxide generation systems. A summary of operation and maintenance requirements is presented in Table 6.

OZONE GENERATION SYSTEMS AND CONTACT CHAMBERS

Construction Cost

Ozone may be generated on-site using either air or pure oxygen. Costs were developed for generation rates between 10 and 3,500 lb/day. For systems up to 100 lb/day, air was assumed to be the feed. At generation rates greater than 100 lb/day, pure oxygen generated on-site is the feed for the ozone generator.

The manufactured equipment cost for ozone generation includes the gas preparation equipment, oxygen generation equipment (at more than 100 lb/day), the ozone generator, dissolution equipment, off gas recycling equipment, electrical and instrumentation costs, and all required safety and monitoring equipment. All ozone-generating equipment was considered to be housed, but

Table 5

Construction Cost for

Chlorine Dioxide Generating and Feed Systems

Cost Category	Chlorine Dioxide Feed Capacity - (lb/day)				
	1	10	100	1,000	5,000
Manufactured Equipment	$ 12,190	$ 13,950	$ 18,740	$ 67,110	$ 116,770
Labor	5,630	8,630	14,440	72,710	127,910
Pipe and Valves	460	940	1,060	5,300	9,300
Electrical and Instrumentation	600	770	1,310	6,560	11,580
Housing	3,620	4,050	10,270	45,940	167,050
SUBTOTAL	22,500	28,340	45,820	197,620	432,610
Miscellaneous and Contingency	3,380	4,250	6,870	29,640	64,890
TOTAL	25,880	32,590	52,690	227,260	497,500

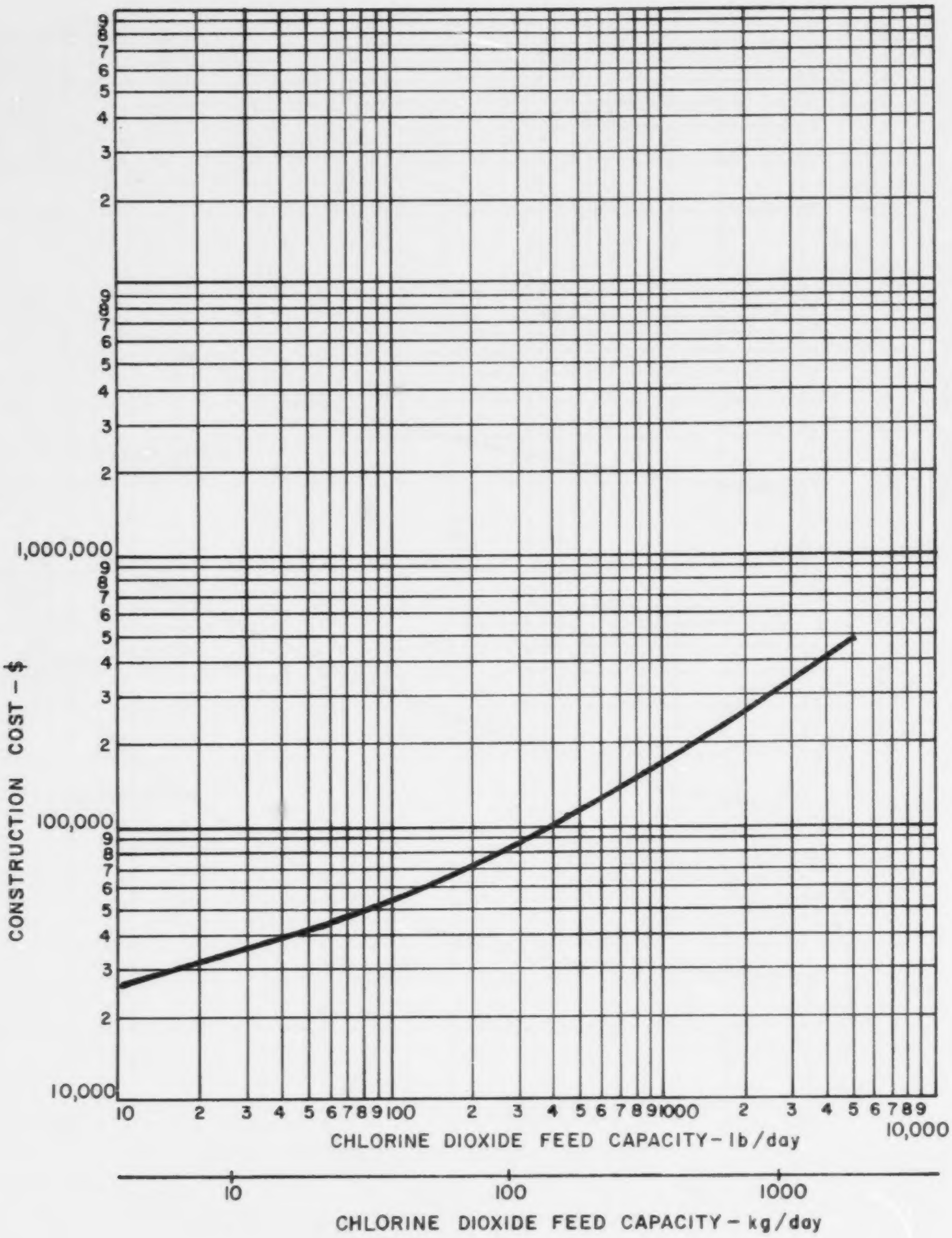


Figure 6. Construction cost for chlorine dioxide generating and feed systems.

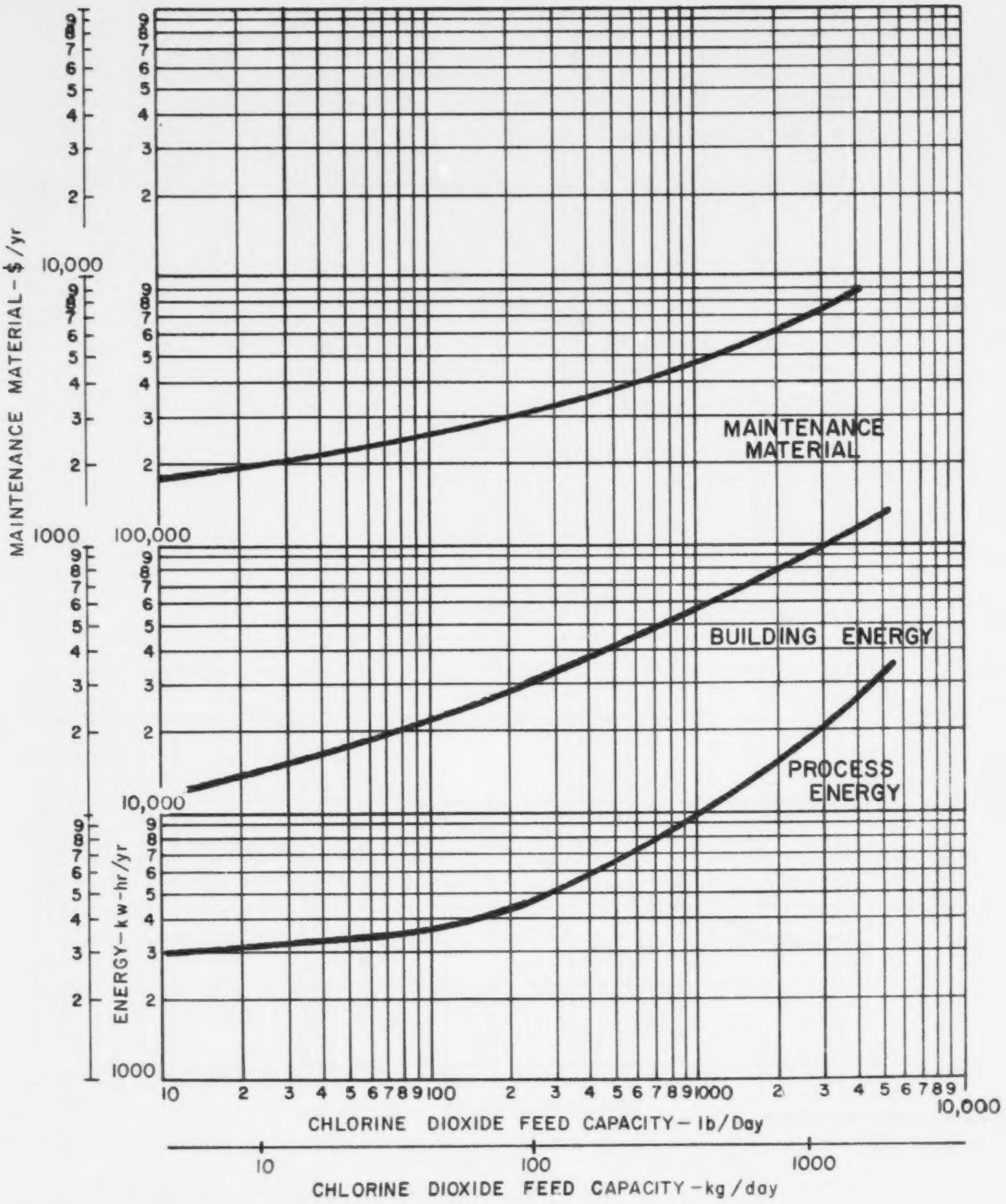


Figure 7. Operation and maintenance requirements for chlorine dioxide generating and feed systems - building energy, process energy, and maintenance material.

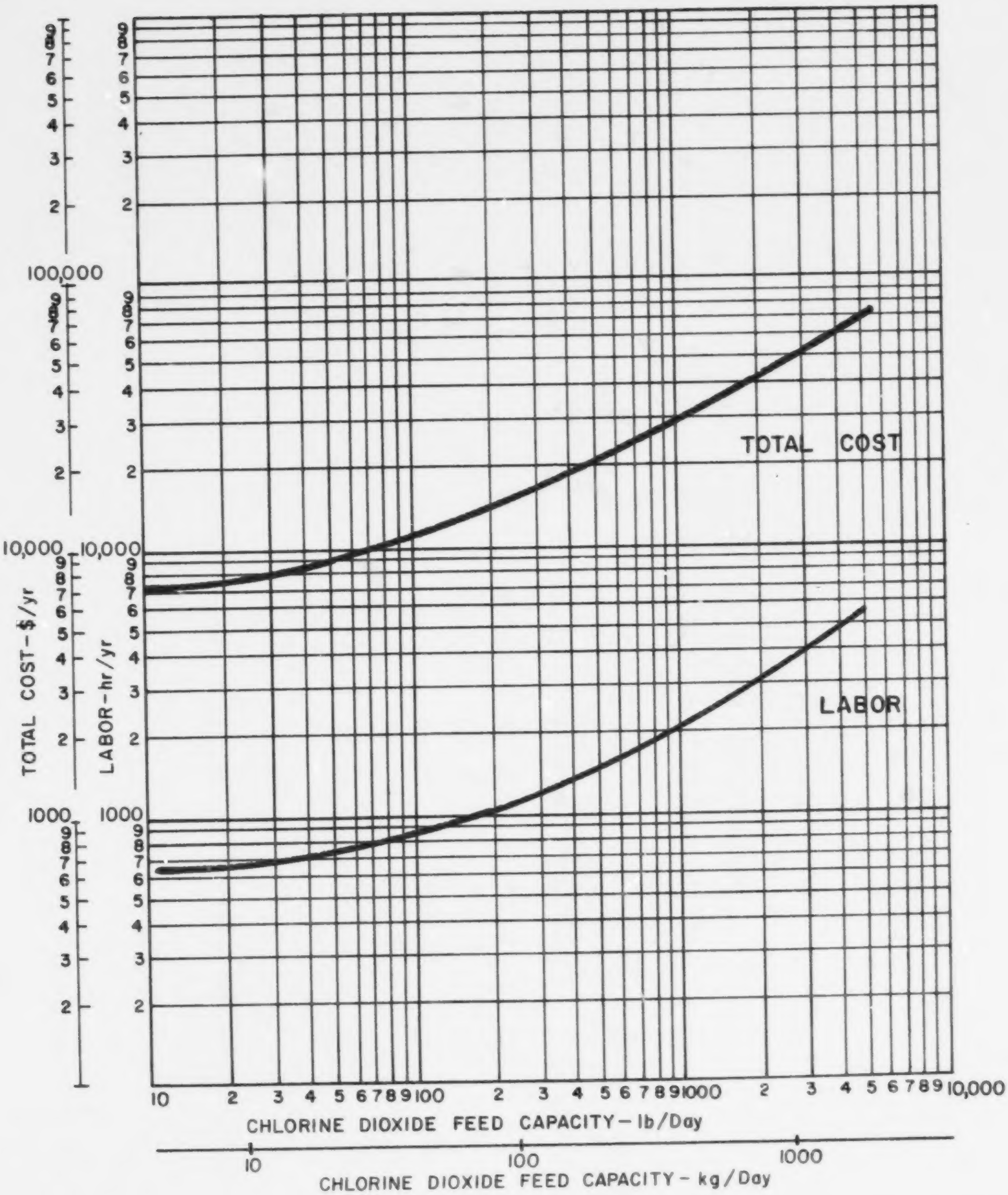


Figure 8. Operation and maintenance requirements for chlorine dioxide generating and feed systems - labor and total cost.

Table 6

Operation and Maintenance Summary for Chlorine Dioxide Generating and Feed Systems

Chlorine Dioxide Feed Rate (lb/day)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
1	12,310	3,290	15,600	$1,110	481	$6,390
10	12,310	3,290	15,600	1,850	604	8,360
100	26,680	3,640	30,320	2,830	873	12,470
1,000	58,480	12,740	71,220	5,160	2,342	30,720
5,000	136,460	35,890	172,350	8,610	5,632	70,100

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

all oxygen-generating equipment is located outside on a concrete slab. Construction costs for ozone-generating systems are shown in Figure 9 and Table 7.

The ozone contact chamber is a covered, reinforced concrete structure with a depth of 18 ft, and a length-to-width ratio of approximately 2:1. Partitions are utilized within the chamber to assure uniform flow distribution. Ozone dissolution equipment costs are included within the ozone generation cost curve and are not included with the ozone contact chamber. Construction costs for contact chambers are shown in Figure 10 and Table 8.

Operation and Maintenance Cost

For ozone generation systems that produce less than 100 lb/day, electrical energy is required for the ozone generator and building heating, cooling, and lighting requirements. Ozone generation using air feed requires 11 kw-hr/lb of ozone generated. For larger, oxygen-fed systems, the power requirements are 7.5 kw-hr/lb of ozone-generated. These figures include oxygen generation, ozone generation, and ozone dissolution.

Maintenance material requirements are for periodic equipment repair and replacement of parts. Based on manufacturers' recommendations, an annual maintenance material requirement of 1 percent of construction cost was utilized.

Labor requirements are for periodic cleaning of the ozone generating apparatus, maintenance of the oxygen generation equipment, annual maintenance of the contact basin, and day-to-day operation of the generation equipment.

Operation and maintenance requirements are shown in Figures 11 and 12 and are summarized in Table 9.

ON-SITE HYPOCHLORITE GENERATION SYSTEMS

Construction Cost

Sodium hypochlorite may be produced in an electrolysis cell using salt, water, and electrical energy. There are presently available two basic types of equipment that generate sodium hypochlorite solution. Open-cell systems have an electrolysis cell that includes an anode and cathode, with the actual cell arrangement varying between manufacturers. Membrane-type systems utilize a cell that has a membrane separating the anode and cathode compartments. A principal difference between the open-cell and membrane systems is the final sodium hypochlorite concentration. Manufacturers report a hypochlorite concentration of about 80,000 mg/l for the membrane cell and only about 5,000 to 8,000 mg/l for the other electrolysis cells. This has a pronounced effect on the required size of the hypochlorite storage facilities and feed systems.

A construction cost curve is shown in Figure 13 for systems with chlorine-producing capacities ranging from 10 to 10,000 lb/day of chlorine equivalent (Note: 1 lb Cl_2 is equivalent to 1.05 lb sodium hypochlorite).

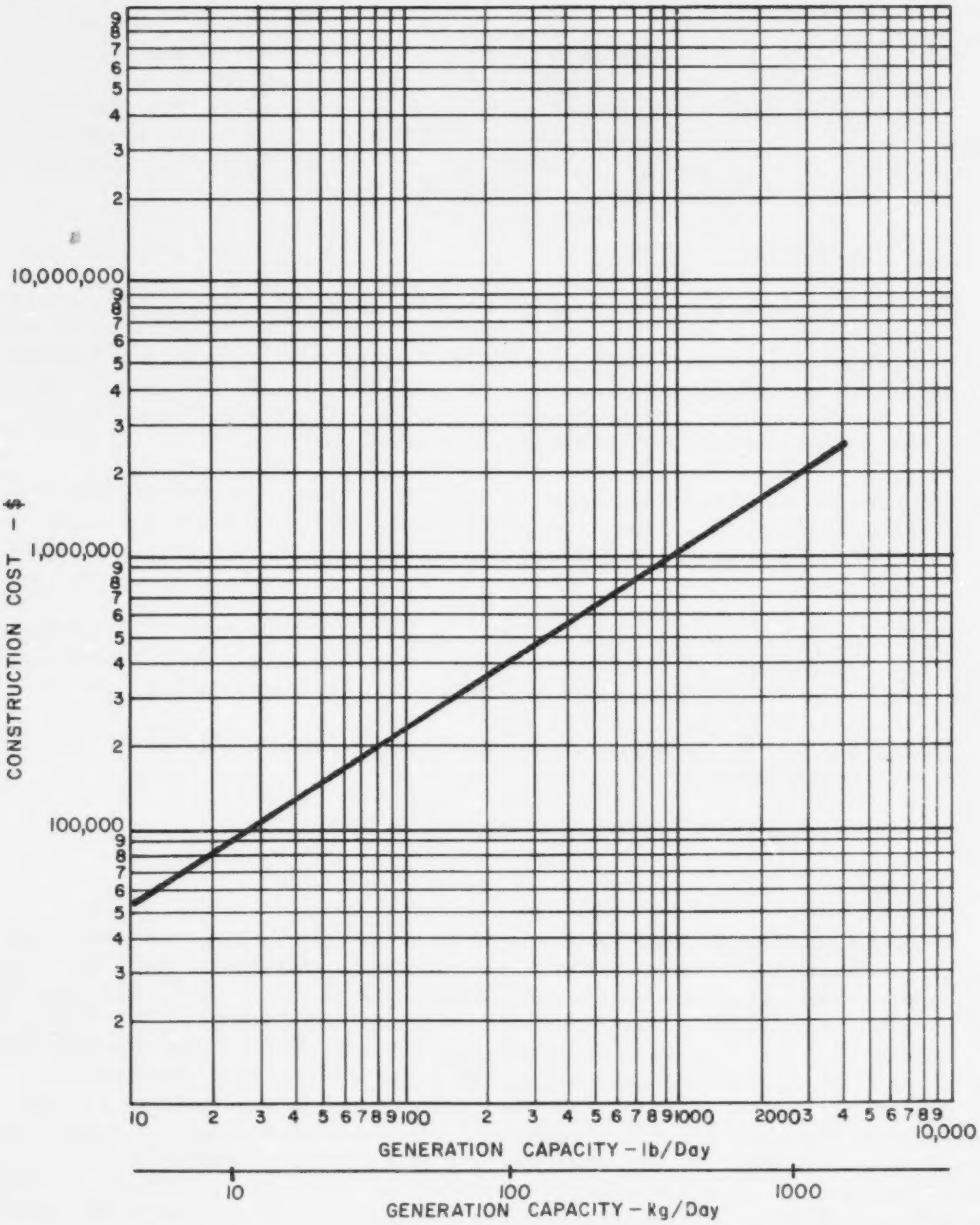


Figure 9. Construction cost for ozone generation systems.

Table 7

Construction Cost for

Ozone Generation Systems

Cost Category	Ozone Generation Capacity - (lb/day)					
	10	100	500	1,000	2,000	3,500
Manufactured Equipment	$ 34,210	$152,350	$543,130	$727,560	$1,135,720	$1,615,980
Concrete	0	0	1,630	1,630	2,380	2,380
Steel	0	0	1,680	1,680	2,440	2,440
Labor	5,090	35,410	120,850	150,420	218,100	286,200
Housing	6,430	9,000	13,600	25,060	38,230	44,770
SUBTOTAL	45,730	196,760	680,890	906,350	1,396,870	1,951,770
Miscellaneous and Contingency	6,860	29,510	102,130	135,950	209,530	292,770
TOTAL	$ 52,590	226,270	783,020	1,042,300	1,606,400	2,244,540

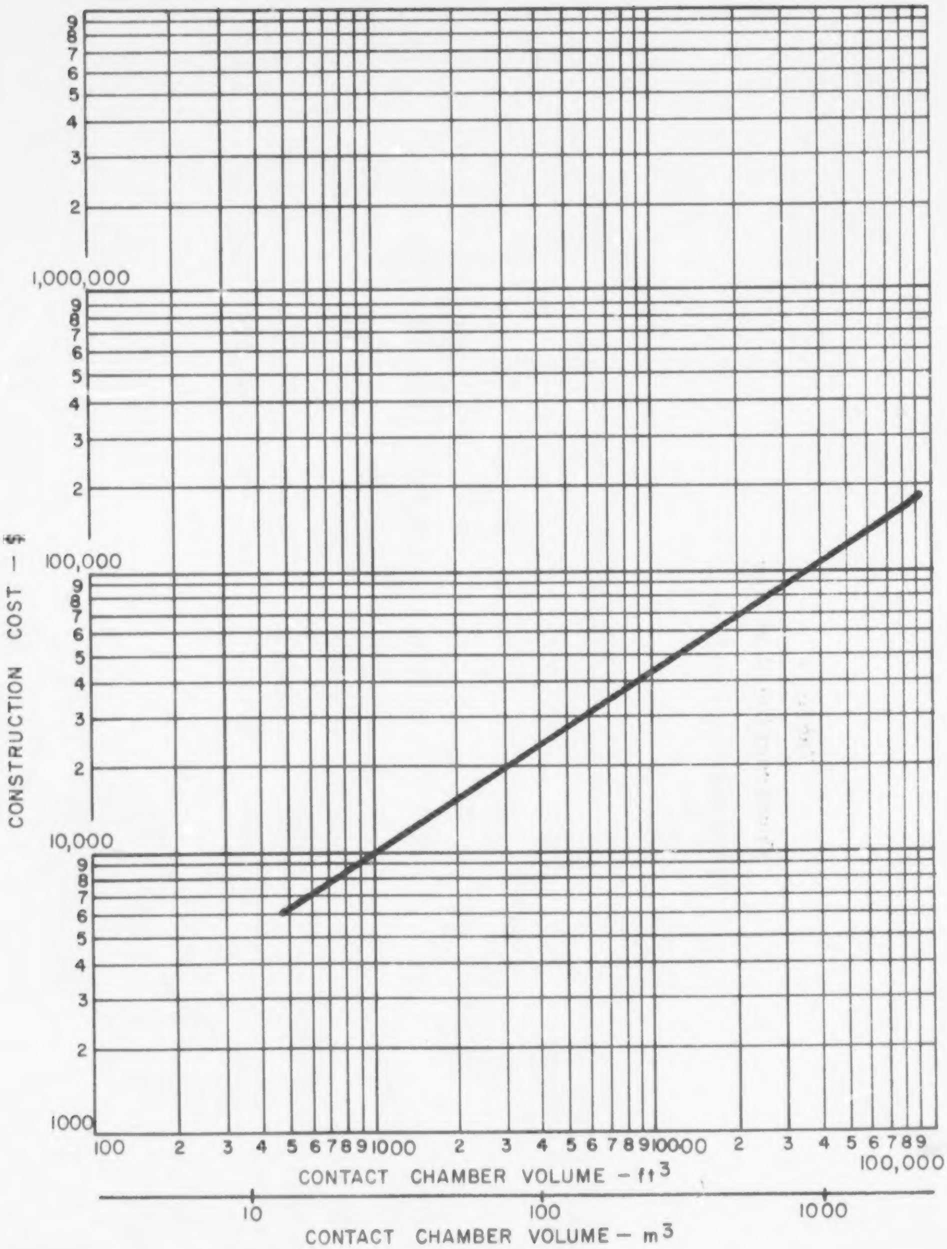


Figure 10. Construction cost for ozone contact chambers.

Table 8

Construction Cost for

Ozone Contact Chambers

Cost Category	Contact Chamber Volume (ft^3)				
	460	4,600	23,000	46,000	92,000
Excavation and Sitework	$ 490	$1,710	$2,700	$5.410	$10.820
Concrete	900	5,250	8,780	16,380	31,600
Steel	1,620	9,270	14,980	25,750	53,580
Labor	2,260	12,820	20,510	37,960	72,870
SUBTOTAL	5,270	29,050	46,970	85,500	168,870
Miscellaneous and Contingency	790	4,360	7,050	12,820	25,330
TOTAL	6,060	33,410	54,020	98,320	194,200

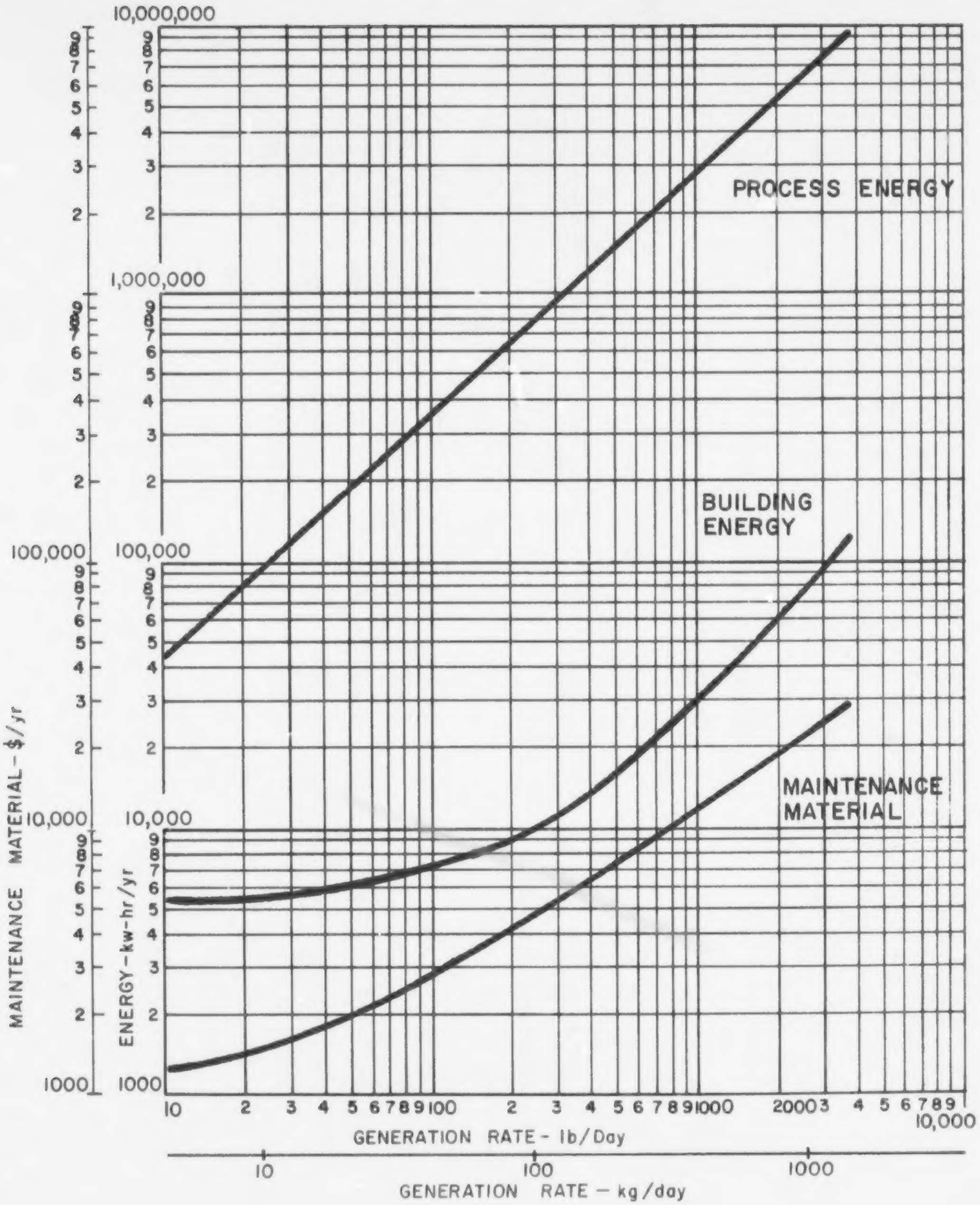


Figure 11. Operation and maintenance requirements for ozone generation systems - building energy, process energy, and maintenance material.

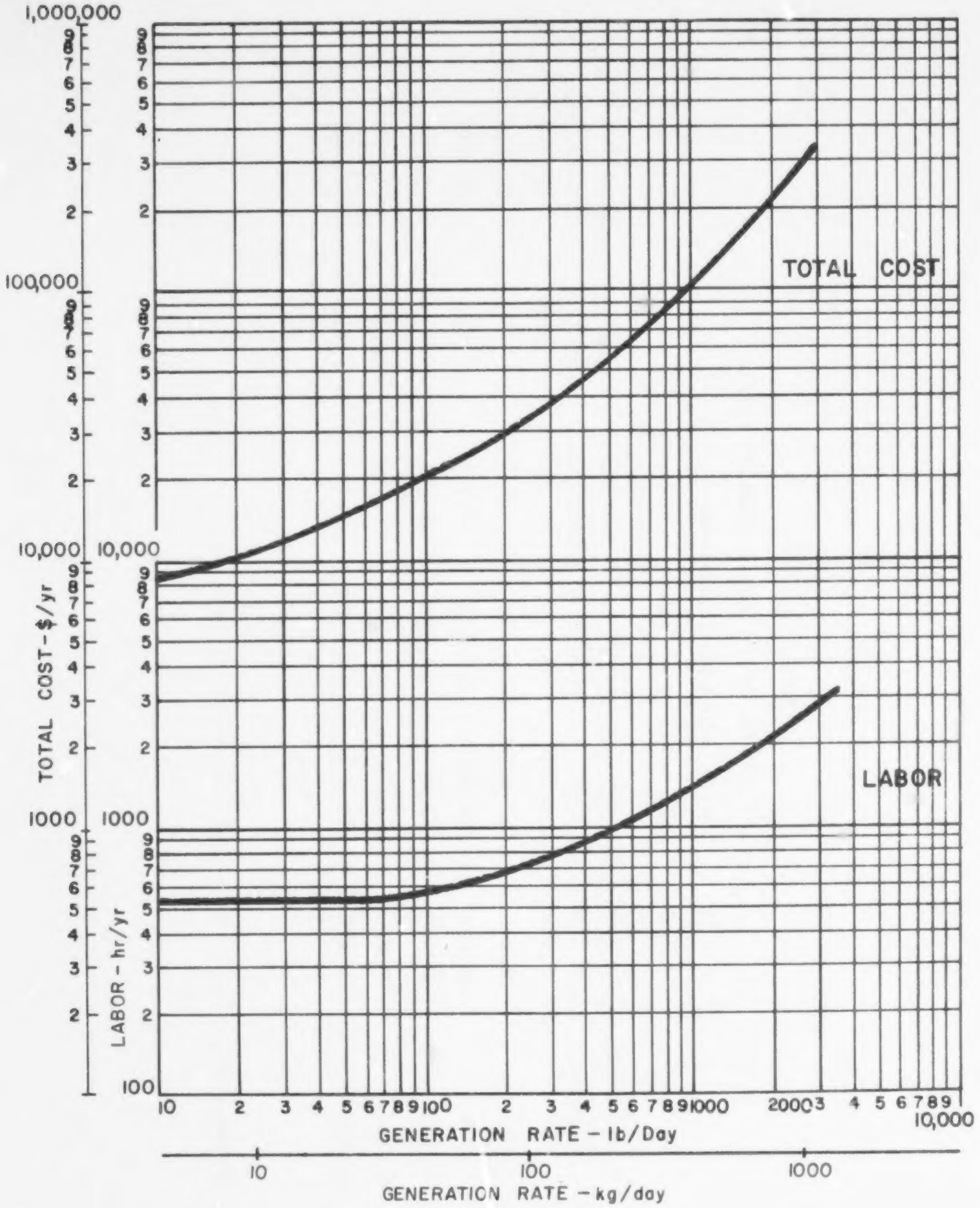


Figure 12. Operation and maintenance requirements for ozone generation systems - labor and total cost.

Table 9

Operation and Maintenance Summary for Ozone Generation Systems

Ozone Generation Rate (lb/day)	Electrical Energy (kw-hr/yr) Building	Electrical Energy (kw-hr/yr) Process	Electrical Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
10	5,750	40,150	45,900	$1,430	550	$8,310
100	9,850	401,500	411,350	3,060	550	20,900
500	16,420	1,368,750	1,385,170	10,770	910	61,430
1,000	30,780	2,737,500	2,768,280	14,270	1,830	115,620
2,000	71,820	5,475,000	5,546,820	22,120	2,190	210,430
3,500	123,120	9,581,250	9,704,370	31,150	2,920	351,480

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

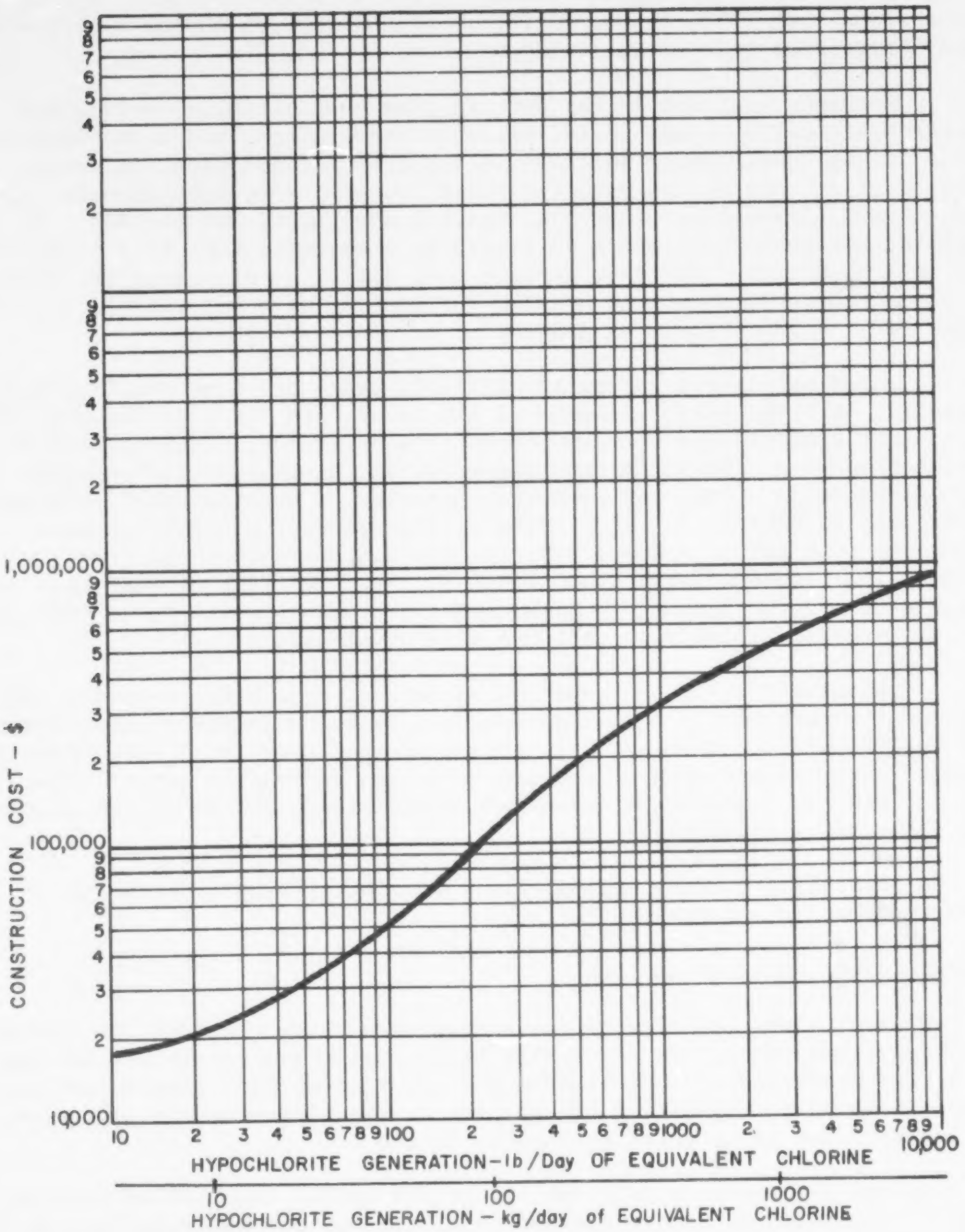


Figure 13. Construction cost for on-site hypochlorite generation.

For systems with a chlorine-producing capacity of up to 2,500 lb/day, the equipment utilized in the cost curve was based on the open-cell systems. For systems from 2,500 to 10,000 lb/day of chlorine, membrane-type systems were utilized because of their lower cost.

Components included in the construction cost estimate include the electrolysis cells, power rectifier, salt storage tank and brine dissolver, brine storage tank, water softener, brine transfer and metering pumps, hypochlorite transfer and metering pumps, hypochlorite storage tank, piping and valves, flowmeters, electrical control equipment, and housing. It was assumed that the hypochlorite is pumped by a metering pump to a location for in-line mixing. The salt storage tank and brine dissolver was assumed to be located outside of the housing for systems with chlorine-producing capacities of 500 lb/day and greater.

A water softener is normally utilized, since cleaning requirements are minimized when the total hardness of the water used for brine make-up is less than 30 mg/l. Use of purified salt is essential, either purchased or purified on-site. Small systems generally use purchased purified salt, but for systems with a chlorine-producing capacity of greater than 2,000 lb/day, it becomes economical to use a brine purification system and the less expensive rock salt. A brine purification system is included in the cost estimate for systems larger than 2,000 lb/day. The salt storage tank and brine dissolver is assumed to have a storage capacity of 1 month, and the sodium hypochlorite storage tank has a 24-hr capacity.

A relatively rapid increase in the cost of hypochlorite-generating equipment occurs as the chlorine-producing capacity increases from about 100 to 500 lb/day. This increase occurs because systems of 100 lb/day and smaller capacity are predesigned and purchased as prefabricated units, whereas most systems of 500 lb/day and larger capacity are custom designed for the particular installation.

A detailed construction cost breakdown for on-site hypochlorite generation systems is presented in Table 10.

Operation and Maintenance Cost

Operation and maintenance costs have been developed from information provided by manufacturers of on-site hypochlorite generation systems and also from operation and maintenance cost guarantees contained in several competitive bids. Operation and maintenance requirements are summarized in Table 11 and illustrated in Figures 14 and 15.

Energy requirements vary from about 2.0 to 4.7 kw-hr/lb of chlorine equivalent, with the lowest energy consumption by the membrane-type cell. Energy requirements were developed using an electrolysis cell and rectifier usage of 2.5 kw-hr/lb of equivalent chlorine. Energy is also required for the electrical control system, the brine transfer and metering pumps, and the sodium hypochlorite transfer and metering pumps. These energy requirements are included under process energy. Electrical energy for lighting, heating, and ventilating is included under building energy.

Table 10

Construction Cost for

On-Site Hypochlorite Generation Systems

Cost Category	Hypochlorite Generation Rate (lb/day Equivalent Chlorine)						
	10	50	250	1,000	2,500	5,000	10,000
Manufactured Equipment	$ 5,940	$ 12,730	$ 68,960	$190,960	$307,660	$424,350	$583,490
Concrete	0	0	0	190	370	370	560
Steel	0	0	0	260	530	530	790
Labor	3,150	5,260	24,170	62,010	97,750	126,130	173,430
Electrical and Instrumentation	1,050	2,460	3,750	14,660	20,940	34,550	34,550
Housing	6,650	7,670	11,120	20,650	23,630	32,710	36,820
SUBTOTAL	16,790	28,120	108,000	288,730	450,880	618,640	829,640
Miscellaneous and Contingency	2,520	4,220	16,200	43,310	67,630	92,800	124,450
TOTAL	19,310	32,340	124,200	332,040	518,510	711,440	954,090

Table 11

Operation and Maintenance Summary for On-Site Hypochlorite Generation Systems

Hypochlorite Generation Rate (lb/day Equivalent Chlorine)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
10	5,130	9,120	14,250	$ 920	330	$4,650
50	10,260	45,600	55,860	1,820	510	8,600
250	30,780	228,000	258,780	3,960	710	18,820
1,000	87,210	912,000	999,210	9,840	1,080	50,620
2,500	99,960	2,280,000	2,379,960	20,630	1,920	111,230
5,000	135,430	4,560,000	4,695,430	37,630	2,700	205,490
10,000	158,300	9,120,000	9,278,300	70,880	3,820	387,430

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

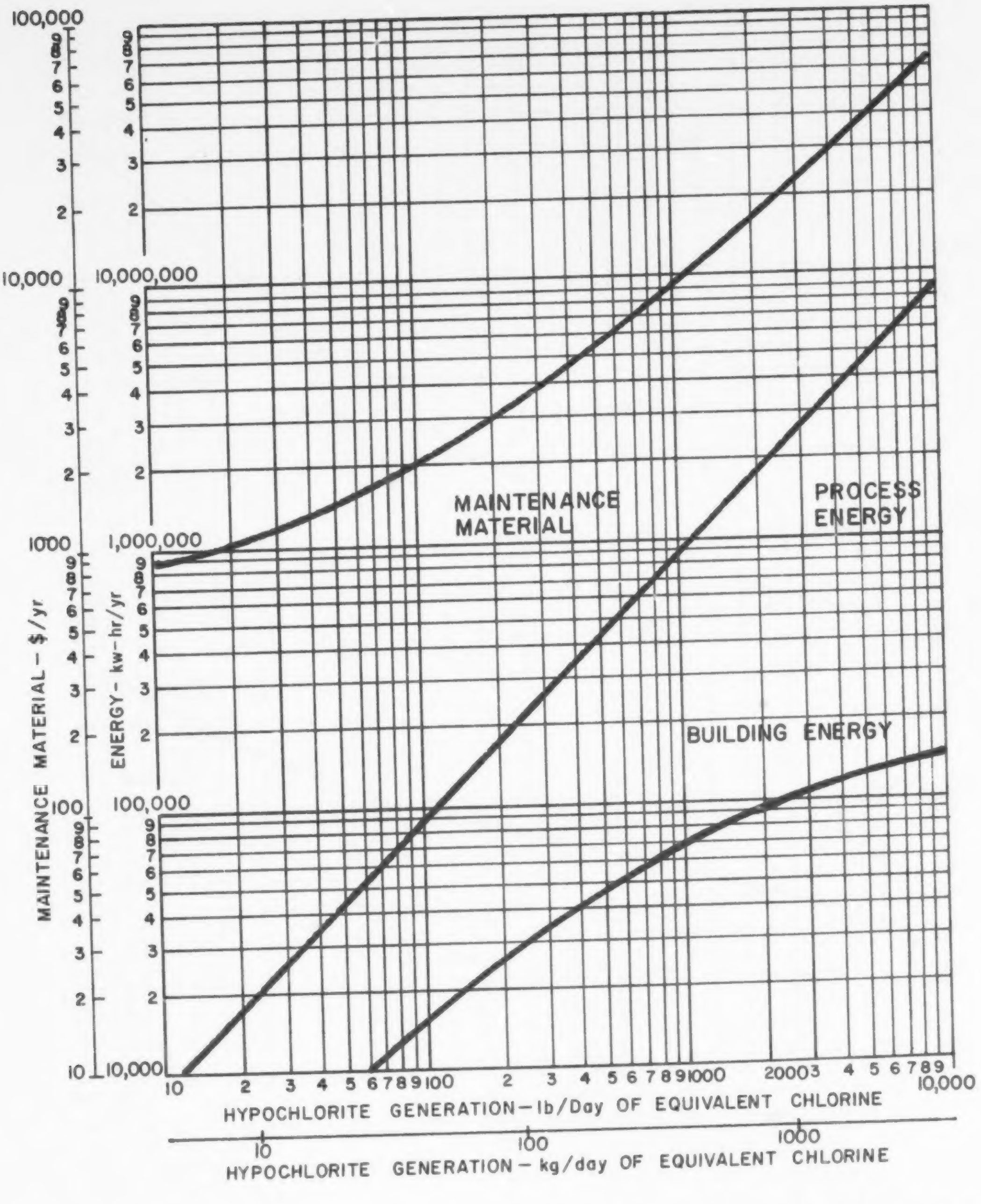


Figure 14. Operation and maintenance requirements for on-site hypochlorite generation systems - building energy, process energy, and maintenance material.

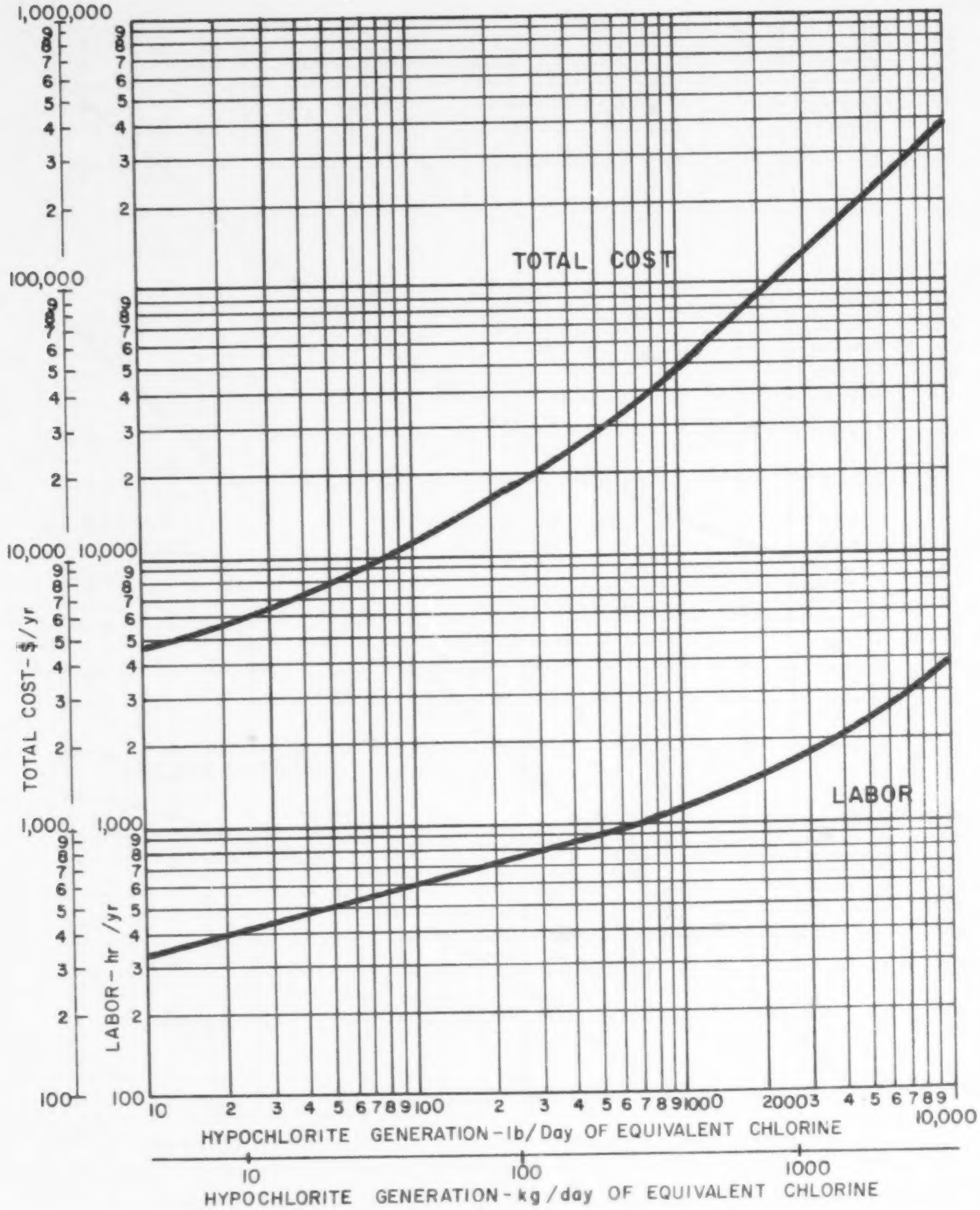


Figure 15. Operation and maintenance requirements for on-site hypochlorite generation systems - labor and total cost.

The largest maintenance material requirement is for electrode replating or replacement. For estimating purposes, it was assumed that the electrodes were replated, or recoated, every 2 years. For the electrolysis cell utilizing a membrane, the entire electrolysis cell (including the anode, cathode, membrane, and cell frame) was assumed to be replaced every 3 years. Other maintenance material requirements are for cell gaskets for the membrane cell, for other miscellaneous parts associated with the electrolysis cells, and for materials needed for periodic repair of pumps, motors, and electrical control equipment. Salt requirements of the different manufactured equipment vary considerably. The reported salt requirements vary from about 2.0 to 4.5 lb of salt/lb chlorine equivalent, with the lowest salt consumption by the membrane-type system. Cost of salt is not included in the cost curves.

Labor requirements are for salt delivery and handling, operation of electrolysis cells, operation and maintenance of pumps, electrode replating or replacing, occasional cleaning of electrolysis cells, and supplying and mixing brine purification chemicals for the larger systems. Labor requirements range from nearly 1 hr/day for the smallest system up to about 11 hr/day for the 1,000 lb/day system. The reduction in the labor requirement for the range from 100 to 200 lb/day of chlorine is attributable to a change in the method of salt delivery, from a more labor intensive use of salt in bags to bulk salt delivery by pneumatic truck. The increase in the range from 1,500 to 2,500 lb/day is due to the added labor required for brine purification, which is included for systems with a chlorine-producing capacity of greater than 2,000 lb/day.

ALUM FEED SYSTEMS

Construction Costs

Liquid Alum--

Costs estimated for liquid alum feed systems are based on use of liquid alum, which has a weight of 10 lb/gal and contains the equivalent of 5 lb of commercial dry alum per gal. Fifteen days of storage are provided, using fiber glass reinforced polyester (FRP) tanks. The FRP tanks were assumed to be uncovered and located indoors for smaller installations, and outdoors for larger installations. Outdoor tanks are covered and vented, with insulation and heating provided to prevent crystallization, which occurs at temperatures below 30°F.

Dual-head metering pumps were used to pump liquid alum from the storage tank and to meter the flow directly to the point of application. No provision was made for dilution of the liquid alum before application. A standby metering pump was included for each installation. All pipe utilized to convey the liquid alum was 316 stainless steel, and 150 ft of pipe, along with miscellaneous fittings and valves, was included for each metering pump.

Construction costs for liquid alum feed are presented in Table 12 and Figure 16.

Table 12

Construction Costs for Liquid Alum Feed Systems

Cost Category	Feed Capacity (lb/hr) 5.4	54	540	5,400
Manufactured Equipment	$ 4,460	$ 5,810	$ 25,410	$ 200,220
Labor	1,000	1,230	4,440	36,340
Pipe and Valves	1,000	1,000	1,000	4,970
Electrical and Instrumentation	3,140	3,400	4,920	14,760
Housing	5,890	14,960	27,670	9,000
SUBTOTAL	15,490	26,400	63,440	265,290
Miscellaneous and Contingency	2,320	3,960	9,520	39,790
TOTAL	17,810	30,360	72,960	305,080

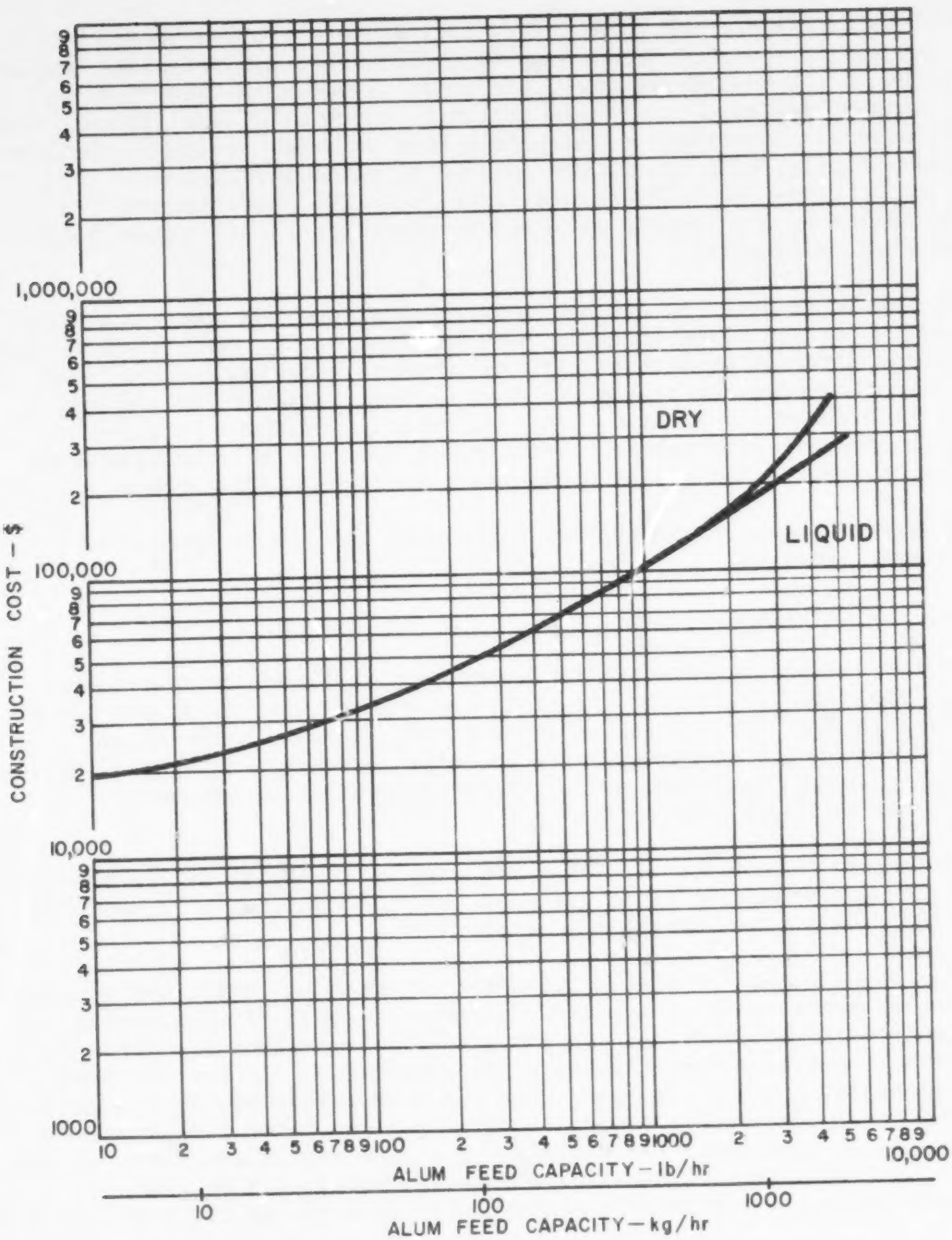


Figure 16. Construction costs for alum feed systems - dry and liquid.

Dry Alum--

Cost estimates for solid alum feed facilities are based on use of commercial dry alum with a density of 60 lb/ft^3. A 5-min detention period is required in the dissolving tank, and 2 gal of water is used/lb alum. Fifteen days of dry alum storage is included, using mild steel storage hoppers located indoors. Conveyance of alum from bulk delivery trucks to the hoppers done pneumatically, with the blower located on the delivery truck. The largest hopper capacity utilized was 6,000 ft^3. For installations too small for bulk delivery, bag loaders are used on the feeder. All hopper facilities included dust collectors.

Volumetric feeders for the smaller installations and mechanical weigh belt feeders for the large installations and their respective solution tanks were located directly beneath the storage hoppers, eliminating the need for bucket elevators or other conveyance devices from below-ground storage. Such installation does, however, make the building cost somewhat greater than other possible arrangements. Conveyance from the solution tanks to the point of application was by dual-head diaphragm metering pumps.

Construction cost estimates for solid alum feed are presented in Table 13 and Figure 16.

Operation and Maintenance Cost

Electrical requirements are for solution mixers, feeder operation, building lighting, ventilation, heating, and (in the case of larger liquid feed installations) for heating of outdoor storage tanks. The sharp decrease in the building energy curve for high feed rates is attributable to the use of outdoor storage tanks, as contrasted to use of indoor storage tanks at lower flow rates.

Maintenance material costs were estimated on the basis of 3 percent of the manufactured equipment cost, excluding storage tank cost. Alum costs are not included in the maintenance material costs.

Labor requirements consist of time for chemical unloading and routine operation and maintenance of feeding equipment. Liquid alum unloading requirements were calculated on the basis of 1.5 hr/bulk truck delivery, and dry alum requirements on the basis of 5 hr/50,000 lb. For dry feed installations using alum from bags, 8 hr was used per 16,000 lb removed and fed to the bag loader hopper. Time for routine inspection and adjustment of feeders is 10 min/feeder per shift for dry feed and 15 min/metering pump per shift of liquid feed. Maintenance requirements were 8 hr/year for liquid metering pumps and 24 hr/year for solid feeders and the solution tank.

Figures 17 to 20 present operation and maintenance costs for both liquid and dry alum feed. A summary of operation and maintenance requirements is presented in Table 14.

Table 13
Construction Costs for
Dry Alum Feed Systems

Cost Category	Feed Capacity (lb/hr) 10	 100	 1,000	 5,000
Manufactured Equipment	$ 7,960	$13,900	$35,600	$170,740
Labor	440	1,190	2,550	12,780
Pipe and Valves	2,130	2,660	3,190	15,940
Electrical and Instrumentation	1,160	2,370	5,190	19,890
Housing	6,430	14,240	54,910	186,980
SUBTOTAL	18,120	34,360	101,440	406,330
Miscellaneous and Contingency	2,720	5,150	15,220	60,950
TOTAL	20,840	39,510	116,660	467,280

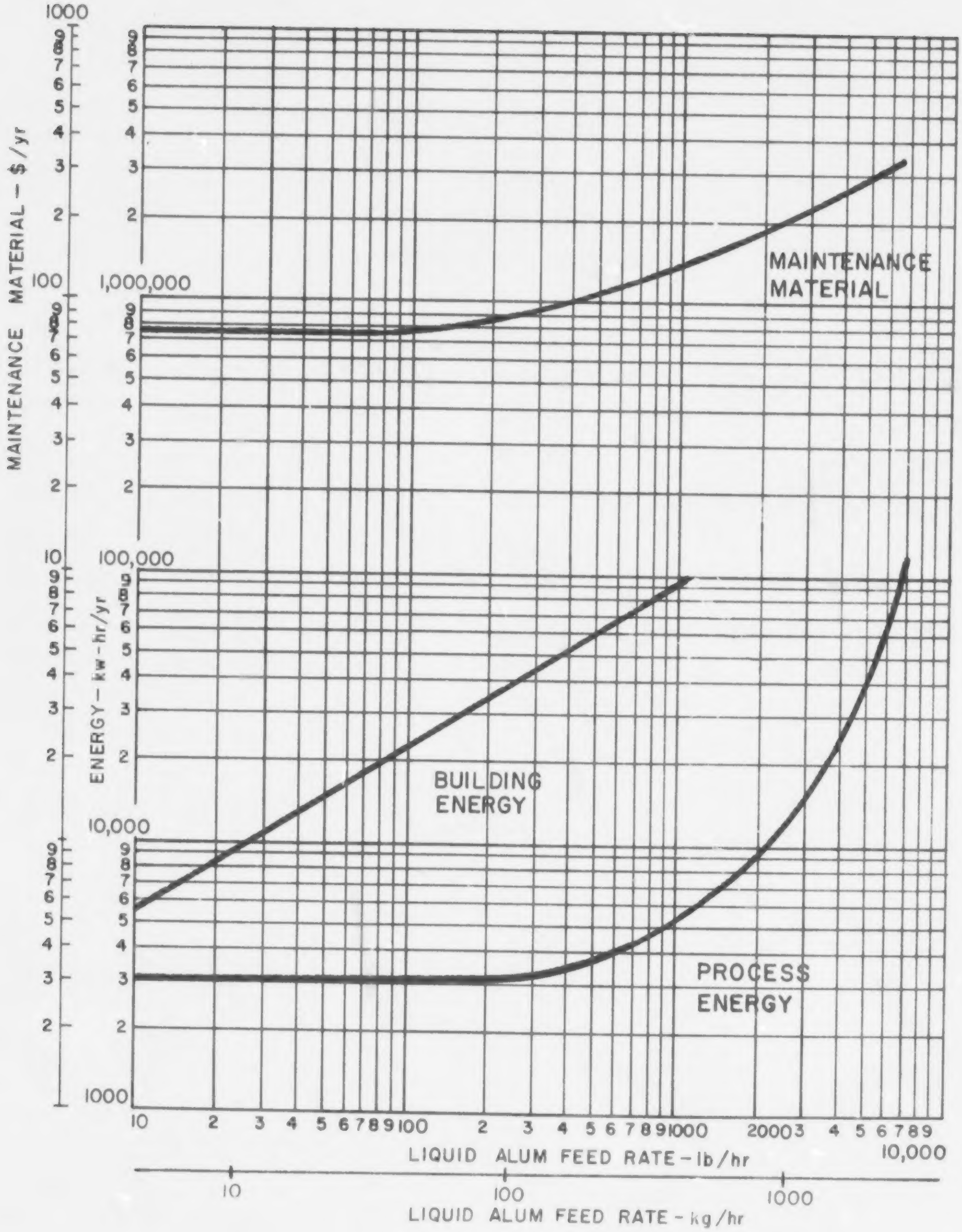


Figure 17. Operation and maintenance requirements for liquid alum feed systems - building energy, process energy, and maintenance material.

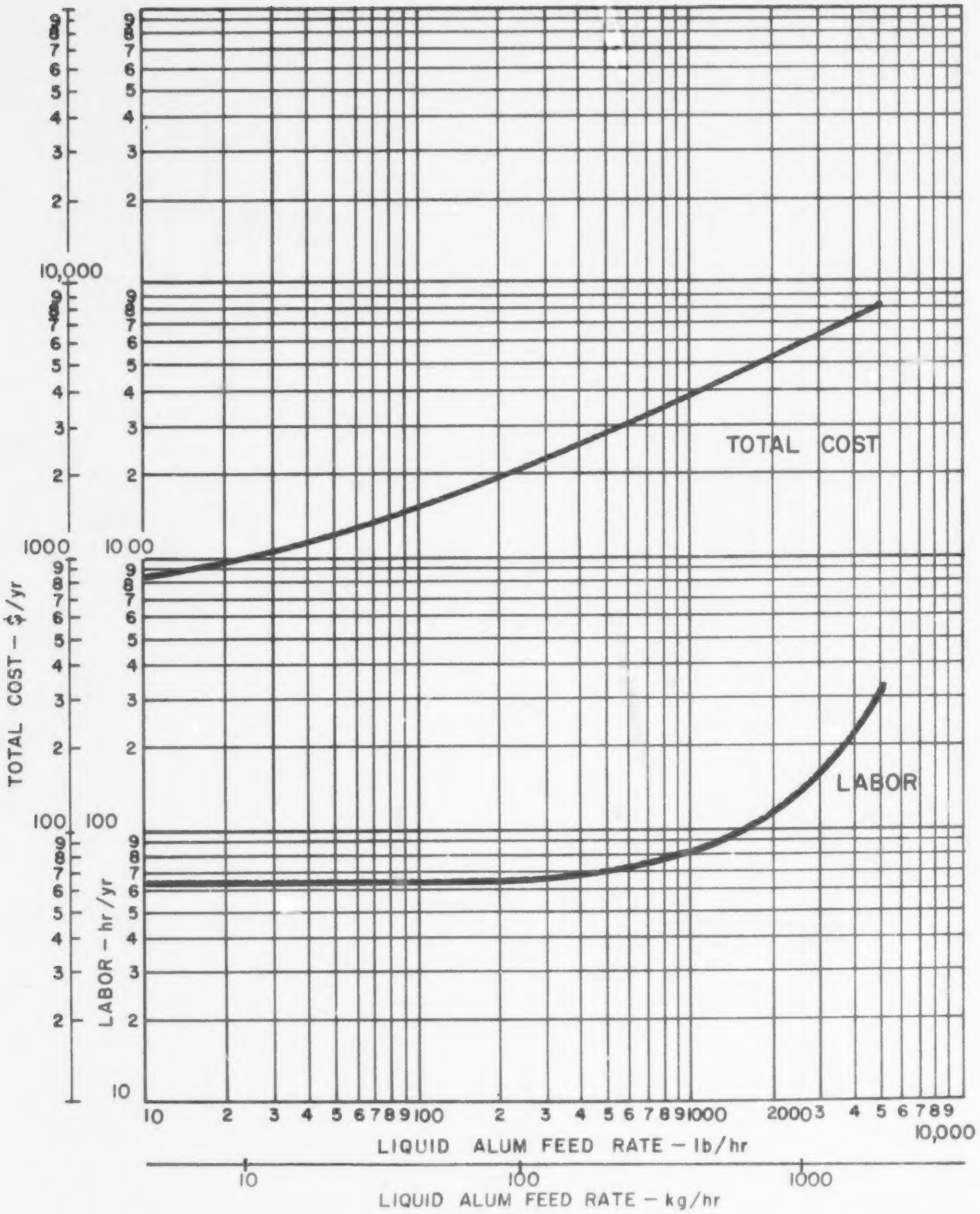


Figure 18. Operation and maintenance requirements for liquid alum feed systems - labor and total cost.

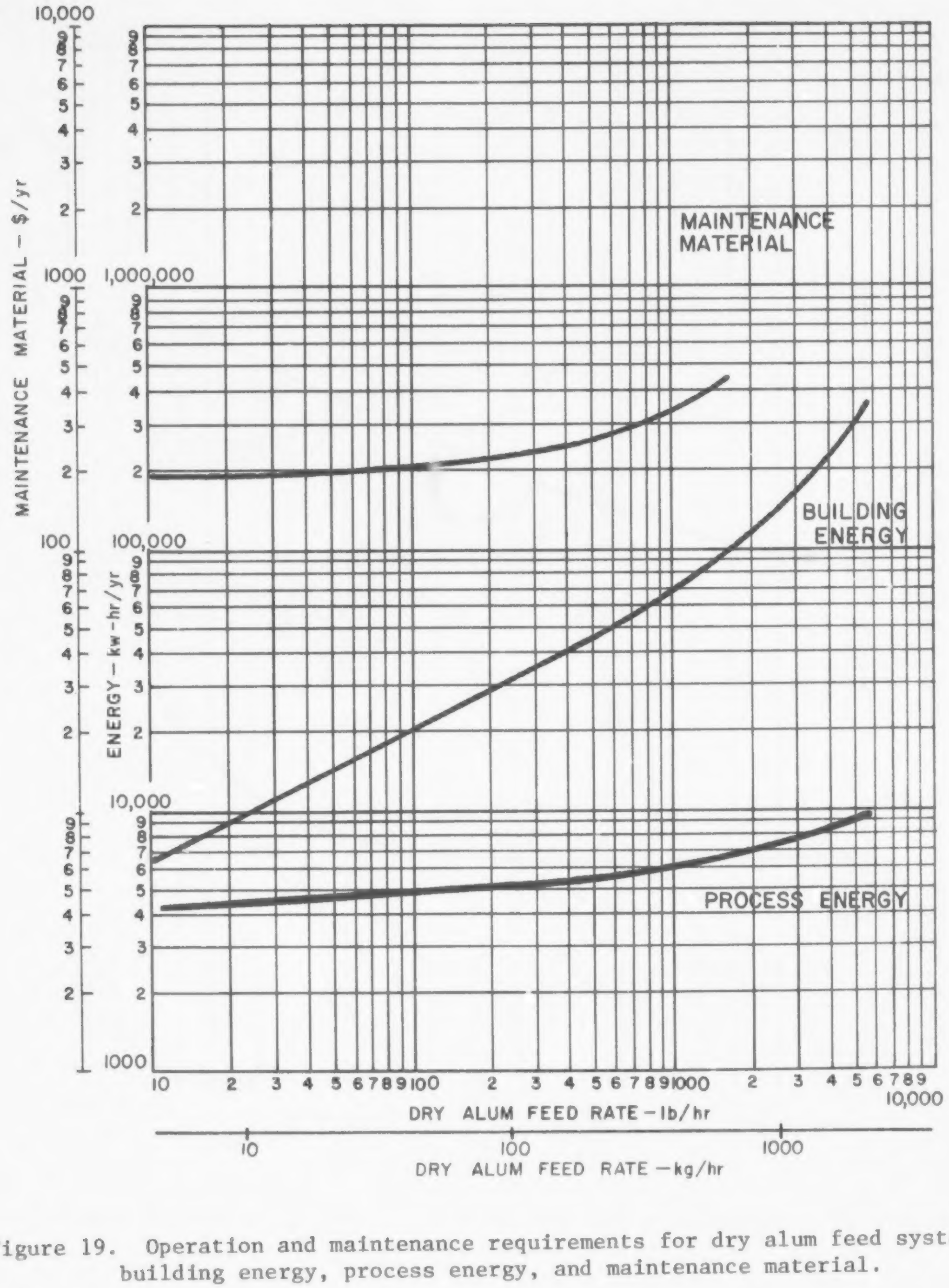


Figure 19. Operation and maintenance requirements for dry alum feed systems - building energy, process energy, and maintenance material.

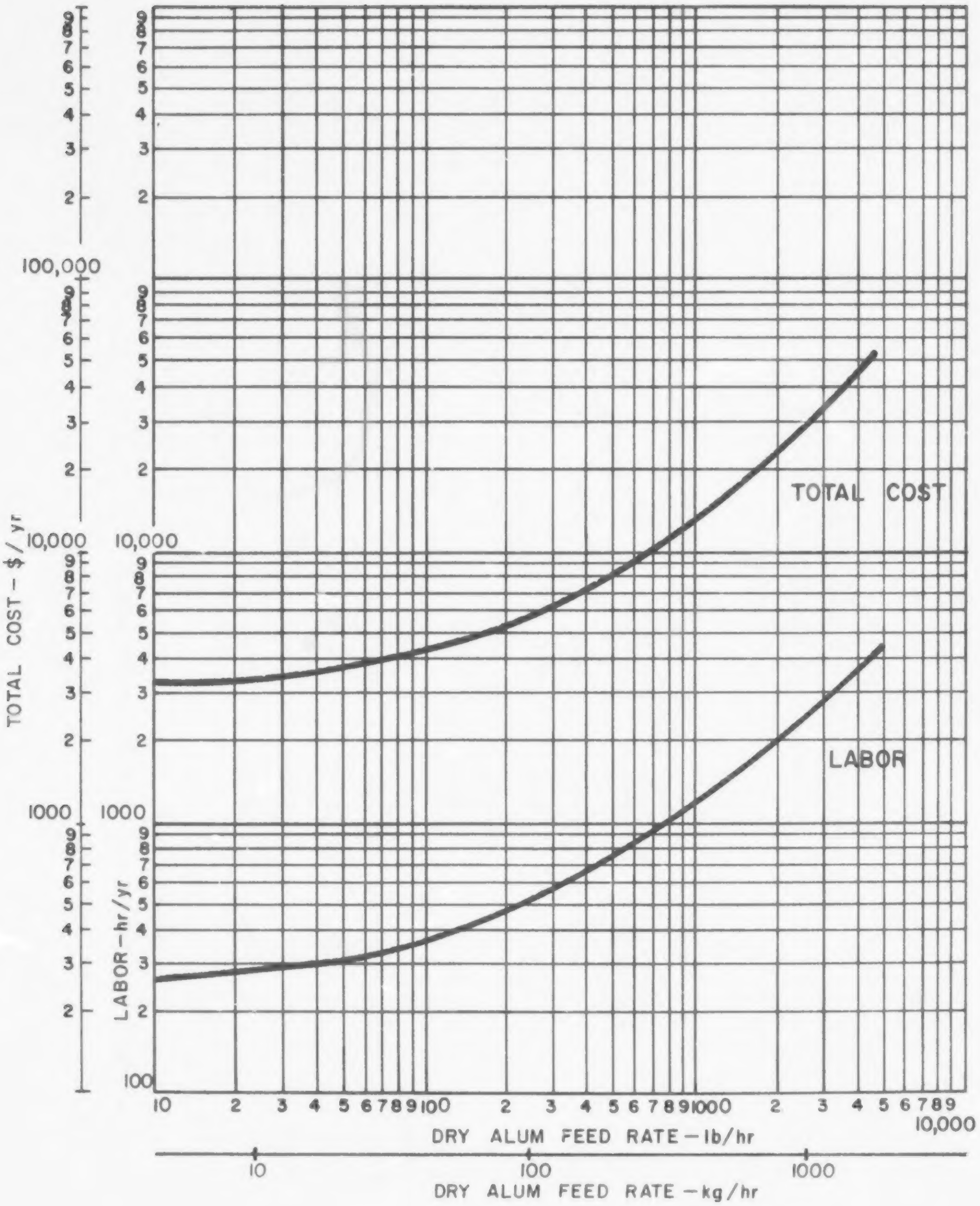


Figure 20. Operation and maintenance requirements for dry alum feed systems - labor and total cost.

Table 14

Operation and Maintenance Summary for Alum Feed Systems

Alum Feed Rate (lb/hr)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
Dry Alum:						
10 lb/hr	6,160	4,900	11,060	$190	288	$3,400
100 lb/hr	23,090	4,900	27,990	220	332	4,380
1,000 lb/hr	63,920	6,530	70,450	320	1,124	13,670
5,000 lb/hr	320,630	9,800	330,430	1,420	4,624	57,570
Liquid Alum:						
5.4 lb/hr	5,130	3,270	8,400	70	63	950
54 lb/hr	24,210	3,270	27,480	70	63	1,520
540 lb/hr	99,520	5,450	104,970	110	63	3,890
5,400 lb/hr	10,260	116,340	126,600	350	315	7,300

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

POLYMER FEED SYSTEMS

Construction Cost

Cost estimates for polymer feed systems are based on the use of dry polymers, fed manually to a storage hopper located on the chemical feeder. Chemical feed equipment is based on preparation of a 0.25-percent stock solution. No provision has been made for standby or redundant equipment, as polymer would generally be utilized only as a coagulant aid or a filter aid, and thus an equipment breakdown could be tolerated for a short period of time while equipment is being repaired.

Costs for polymer feed systems are presented in Table 15 and Figure 21.

Operation and Maintenance Cost

Energy requirements for the feeder and metering pump were calculated using motor horsepower requirements recommended by manufacturers. Building energy requirements are based on completely housed systems.

Maintenance material costs used are 3 percent of manufactured equipment and pipe/valve costs. These costs do not include the cost of polymer.

Labor requirements are for bag unloading (1 hr/ton of bags), the dry chemical feeder (110 hr/year for routine operation and 24 hr/year for maintenance), and the solution metering pump (55 hr/year for routine operation and 8 hr/year for maintenance).

Figures 22 and 23 present the estimated operation and maintenance requirements for feeding of a 0.25-percent polymer solution. The operation and maintenance requirements are summarized in Table 16.

LIME FEED SYSTEMS

Construction Cost

Construction costs were developed for lime feed systems that used hydrated lime at feed rates up to 50 lb/hr and quicklime at higher rates. Two curves were developed for quicklime - one that used new lime, and one that used a combination of new and recalcined lime. The use of recalcined lime lowers the storage requirement and therefore decreases the cost of the lime feed facilities for a given capacity.

Hydrated lime was assumed to be purchased in 100-lb bags and to be fed using either a volumetric or gravimetric feeder to a dissolving tank having a 5-min detention time. In the dissolving tank, the lime is mixed to a 6-percent slurry and fed by gravity to the point of application.

Table 15
Construction Costs for
Polymer Feed Systems

Cost Category	Polymer Feed Capacity (lb/day) 1	10	100	200
Manufactured Equipment	$ 11,670	$ 11,670	$ 14,730	$18,970
Labor	700	700	700	760
Pipe and Valves	280	280	280	300
Electrical and Instrumentation	1,290	1,290	1,290	1,290
Housing	3,600	3,600	4,050	4,500
SUBTOTAL	17,540	17,540	21,050	25,820
Miscellaneous and Contingency	2,630	2,630	3,160	3,870
TOTAL	20,170	20,170	24,210	29,690

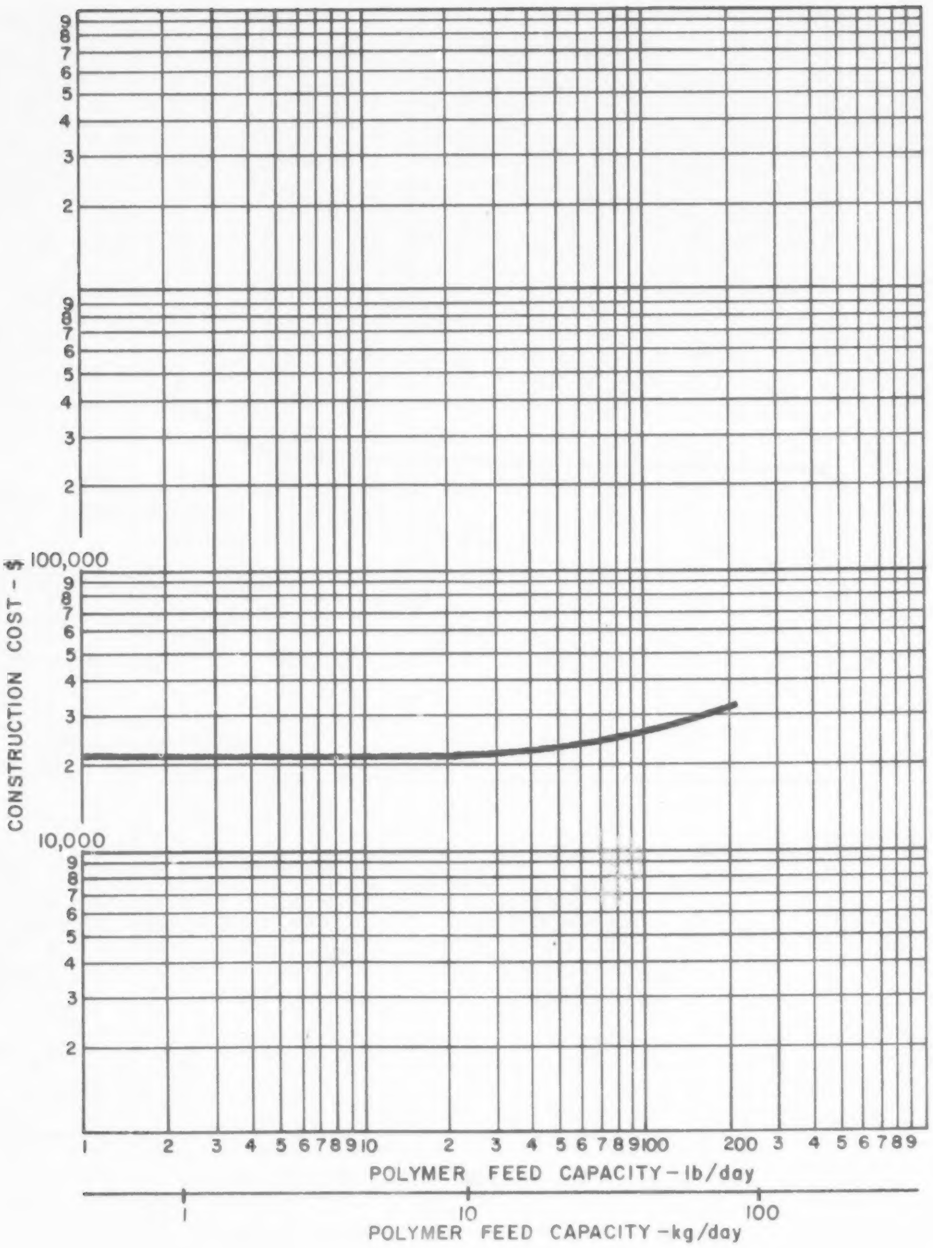


Figure 21. Construction cost for polymer feed systems.

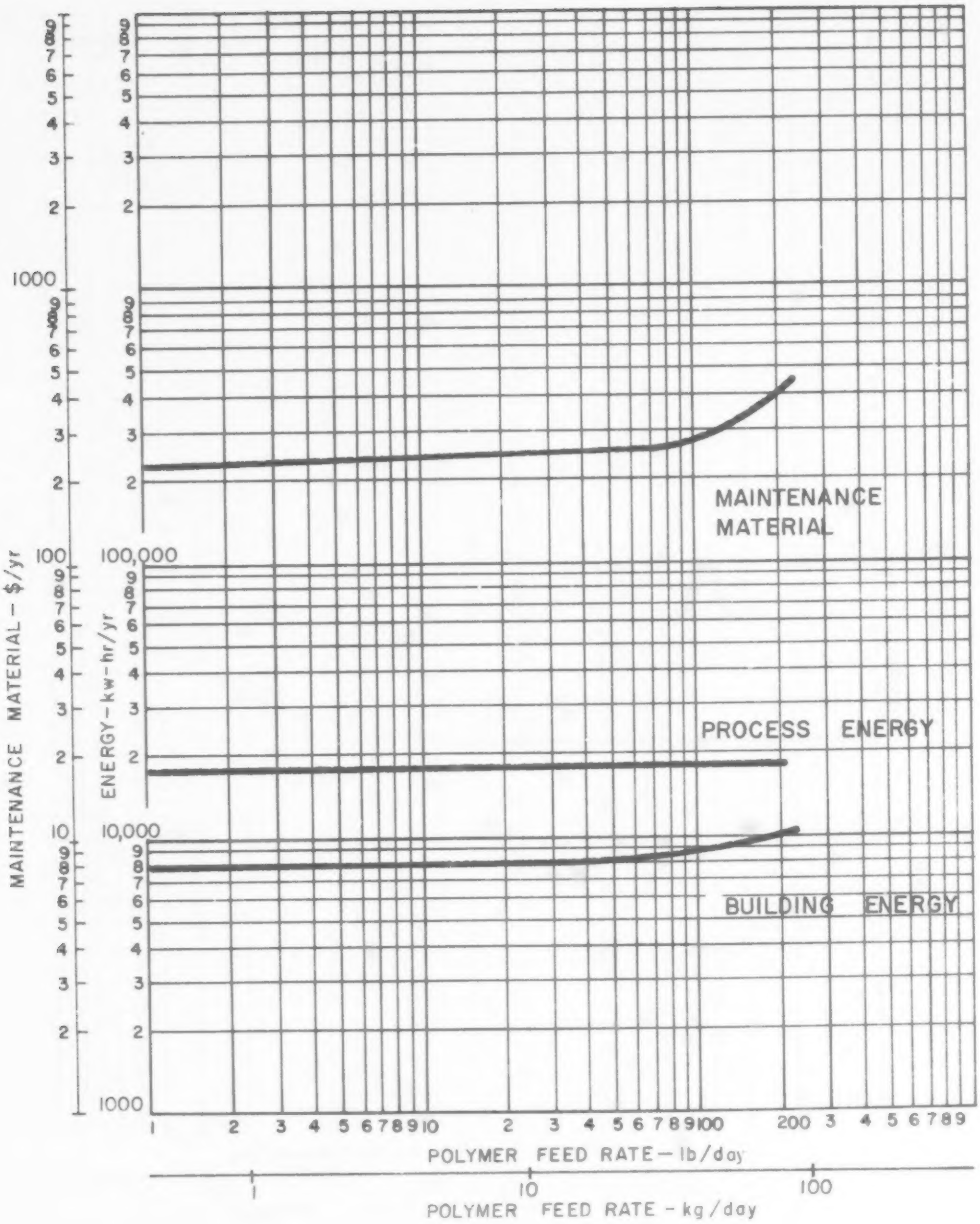


Figure 22. Operation and maintenance requirements for polymer feed systems - building energy, process energy, and maintenance material.

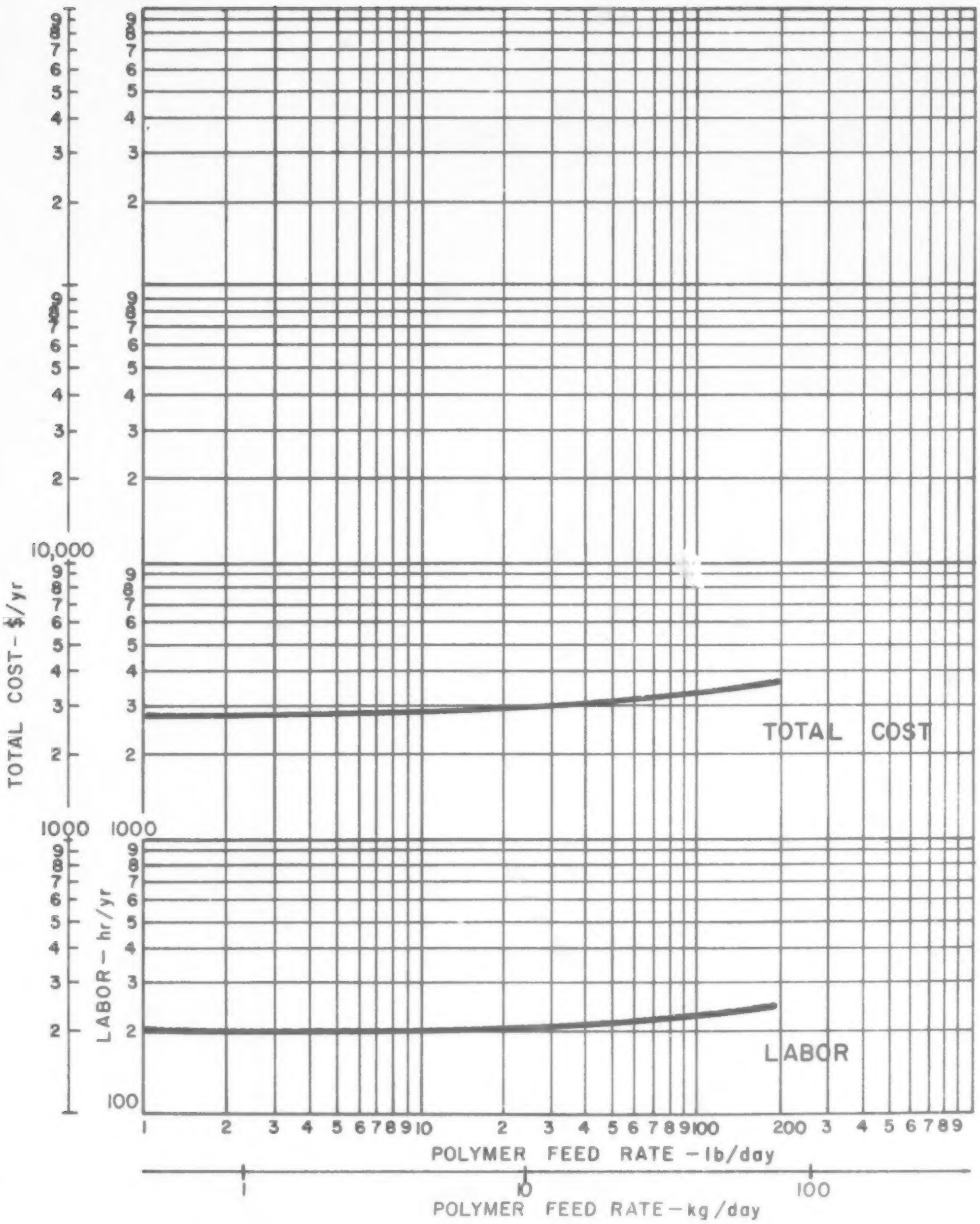


Figure 23. Operation and maintenance requirements for polymer feed systems - labor and total cost.

Table 16

Operation and Maintenance Summary for Polymer Feed Systems

Polymer Feed Rate (lb/day)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1	8,210	17,300	25,510	260	198	3,010
10	8,210	17,300	25,510	280	199	3,040
100	9,230	17,300	26,530	310	215	3,260
200	10,260	17,300	27,560	470	234	3,640

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Quicklime is purchased in bulk, with 90 percent purity and a density of 60 lb/ft^3, and stored in elevated hoppers above the lime slakers. Lime is conveyed pneumatically from delivery truck to the storage hopper. Hoppers include a dust collector, bin gate, and flexible connection to the slaker. Hoppers were sized for a 30 day storage of lime, except when recalcination is used (then only a 3 day storage of the new lime was provided). The slaker mixes water with lime on a 2:1 weight basis, and the lime slurry is conveyed in an open gravity channel to the application point. Although all applications may not be able to use gravity conveyance in a channel, it is highly recommended from a maintenance standpoint. Standby slakers are included for all installations using quicklime.

Estimated construction costs are presented in Figure 24 and Table 17.

Operation and Maintenance Cost

Process energy requirements are for the feeder, slaker, and grit removal and are based on motor sizes for the various equipment. Annual maintenance material costs were based on 3 percent of manufactured equipment costs, excluding the cost of the storage hopper. Lime cost is not included in the maintenance material costs.

Labor requirements for unloading are 5 hr/50,000 lb for bulk delivery and 8 hr/16,000 lb for bag delivery and feed. Operation and maintenance time for the lime feeder, the slaker, and the associated grit removal is 3 hr/feeder per slaker per day. For smaller installations using hydrated lime, a routine operation time of 20 min/day was used for the solid feeder and the solution tank.

Annual operation and maintenance requirements are presented in Figures 25 and 26. A summation of operation and maintenance requirements is presented in Table 18.

POTASSIUM PERMANGANATE FEED SYSTEMS

Construction Cost

Cost estimates were developed for facilities using dry, 97 percent pure potassium permanganate purchased in drums and mixed to solution on-site. Solutions are mixed to 4 percent on a daily basis and fed from the day tank using a dual-head diaphragm pump. For very low dosage rates, a dilution to 0.4 percent is necessary to produce a large enough volume to feed with the metering pump. Storage is provided for 15 days of dry potassium permanganate. Standby metering pumps are included for all installations.

Estimated construction costs are shown in Table 19 and Figure 27.

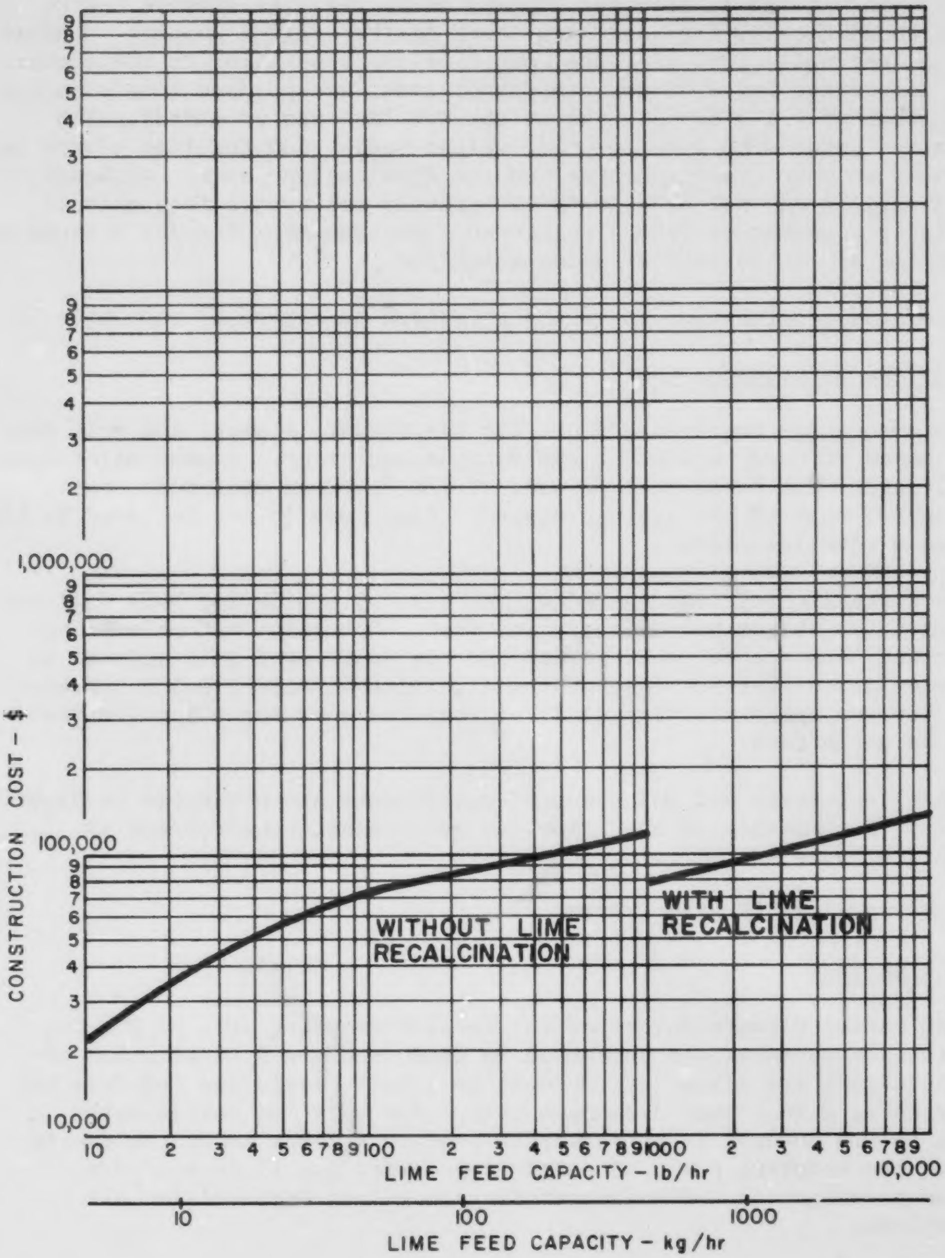


Figure 24. Construction cost for lime feed systems.

Table 17

Construction Cost for

Lime Feed Systems

Cost Category	Lime Feed Capacity (lb/hr)				
	Without Lime Recalcination			With Lime Recalcination	
	10	100	1,000	1,000	10,000
Manufactured Equipment	$ 5,400	$ 44,870	$ 62,160	$ 48,870	$ 80,660
Labor	420	1,240	1,510	1,510	3,060
Pipe and Valves	2,500	2,500	3,120	3,120	6,250
Electrical & Instrumentation	1,440	6,880	6,880	6,880	12,320
Housing	9,450	9,450	26,250	9,450	26,250
SUBTOTAL	19,210	64,940	99,920	69,830	128,540
Miscellaneous & Contingency	2,880	9,740	14,990	10,470	19,280
TOTAL	22,090	75,680	114,910	80,300	147,820

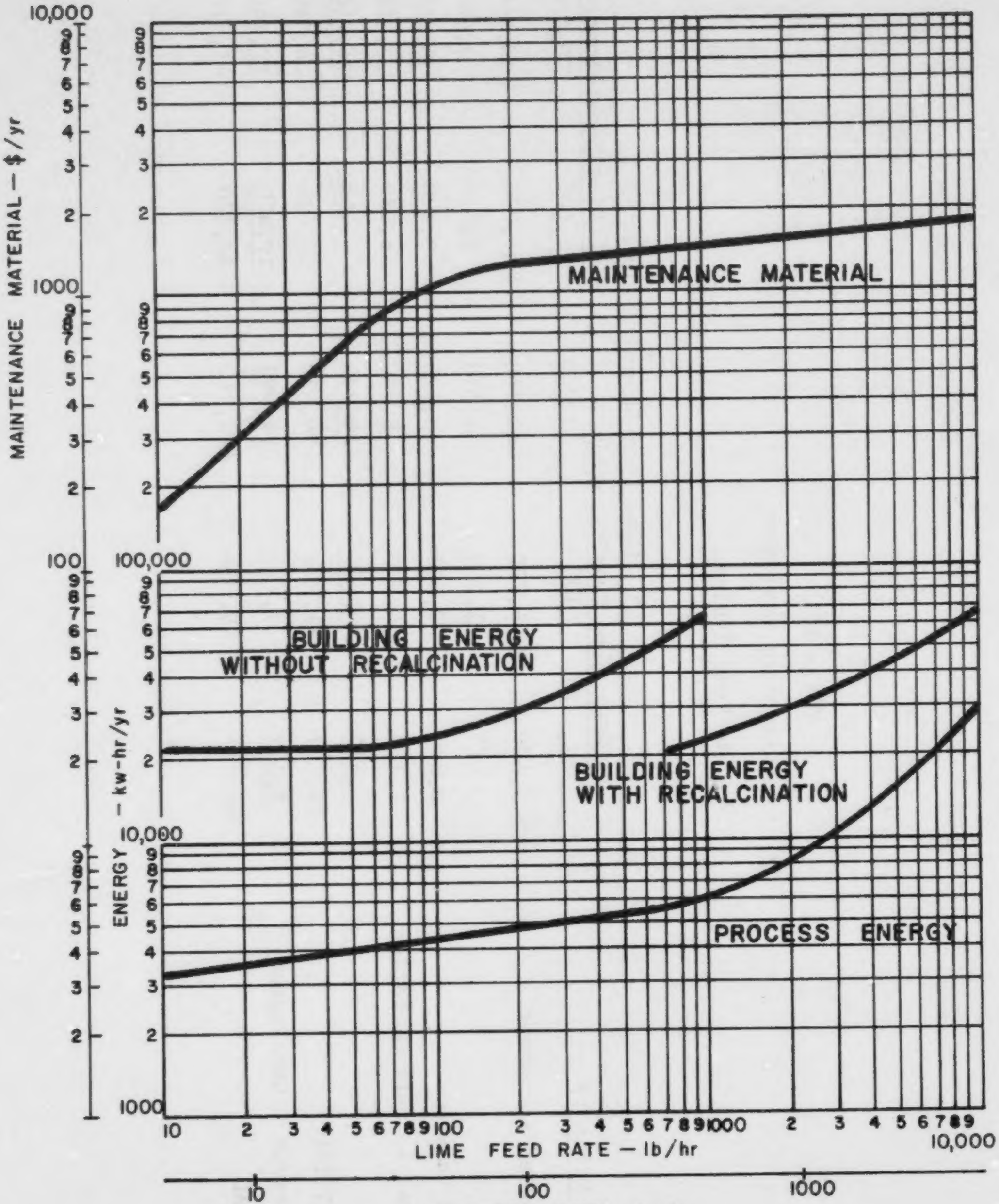


Figure 25. Operation and maintenance requirements for lime feed systems - building energy, process energy and maintenance material.

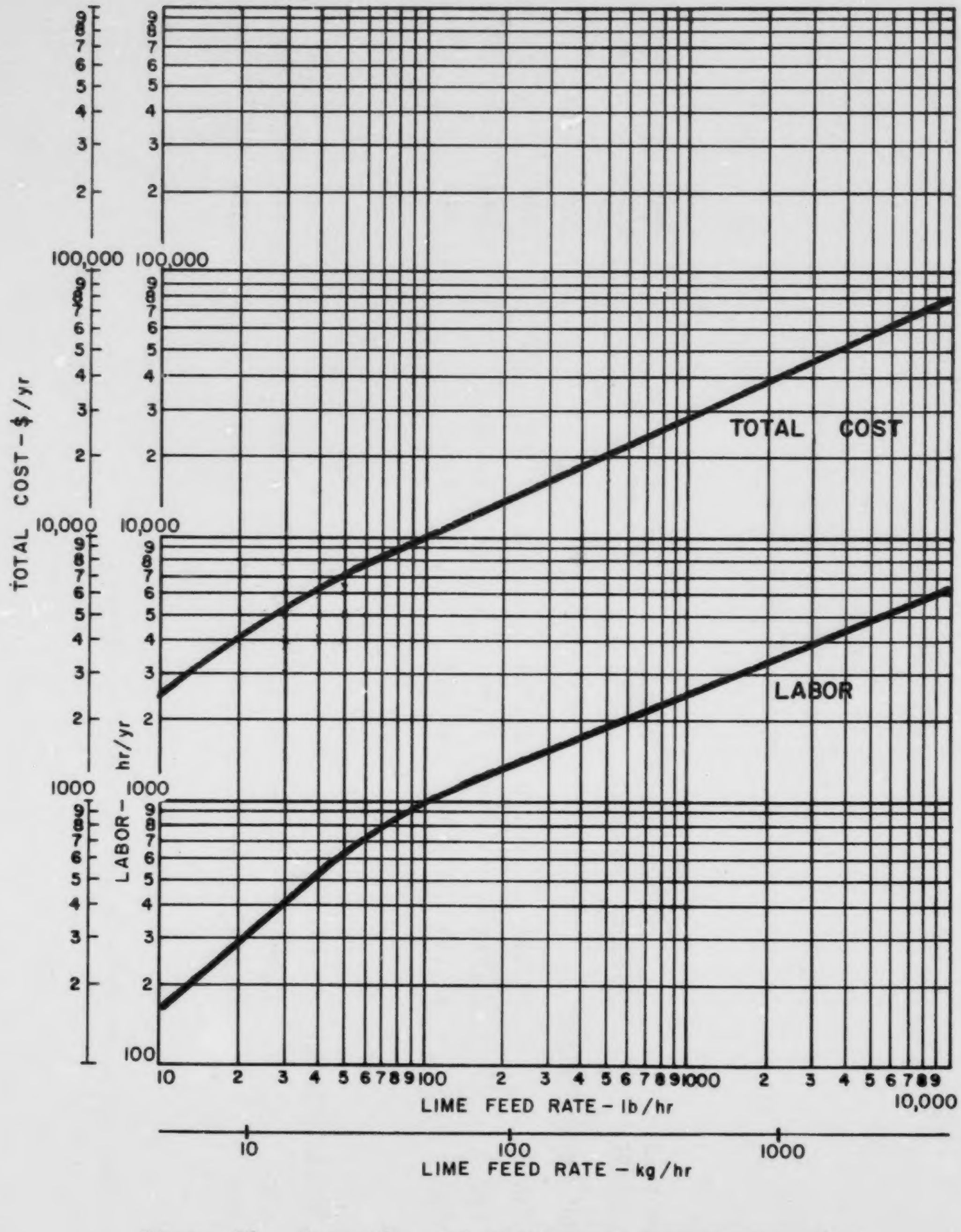


Figure 26. Operation and maintenance requirements for lime feed systems - labor and total cost.

Table 18

Operation and Maintenance Summary
for Lime Feed Systems

Lime Feed Rate (lb/hr)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
Without Recalcination:						
10	23,090	3,270	26,360	$ 160	166	$ 2,610
100	23,090	4,900	27,990	1,240	1,183	13,910
1,000	64,130	4,900	69,030	1,360	1,975	23,180
With Recalcination:						
1,000	23,090	4,900	27,990	1,360	1,975	21,950
10,000	64,130	29,390	93,520	1,910	6,570	70,420

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 19

Construction Cost for
Potassium Permanganate Feed Systems

Cost Category	Feed Capacity (lb/day) 1	10	100	500
Manufactured Equipment	$2,340	$ 2,600	$ 3,380	$ 5,220
Labor	480	480	540	770
Pipe and Valves	970	970	970	970
Electrical & Instrumentation	3,190	3,190	3,190	3,190
Housing	1,260	1,580	1,950	2,940
SUBTOTAL	8,240	8,820	10,030	13,090
Miscellaneous & Contingency	1,240	1,320	1,500	1,960
TOTAL	9,480	10,140	11,530	15,050

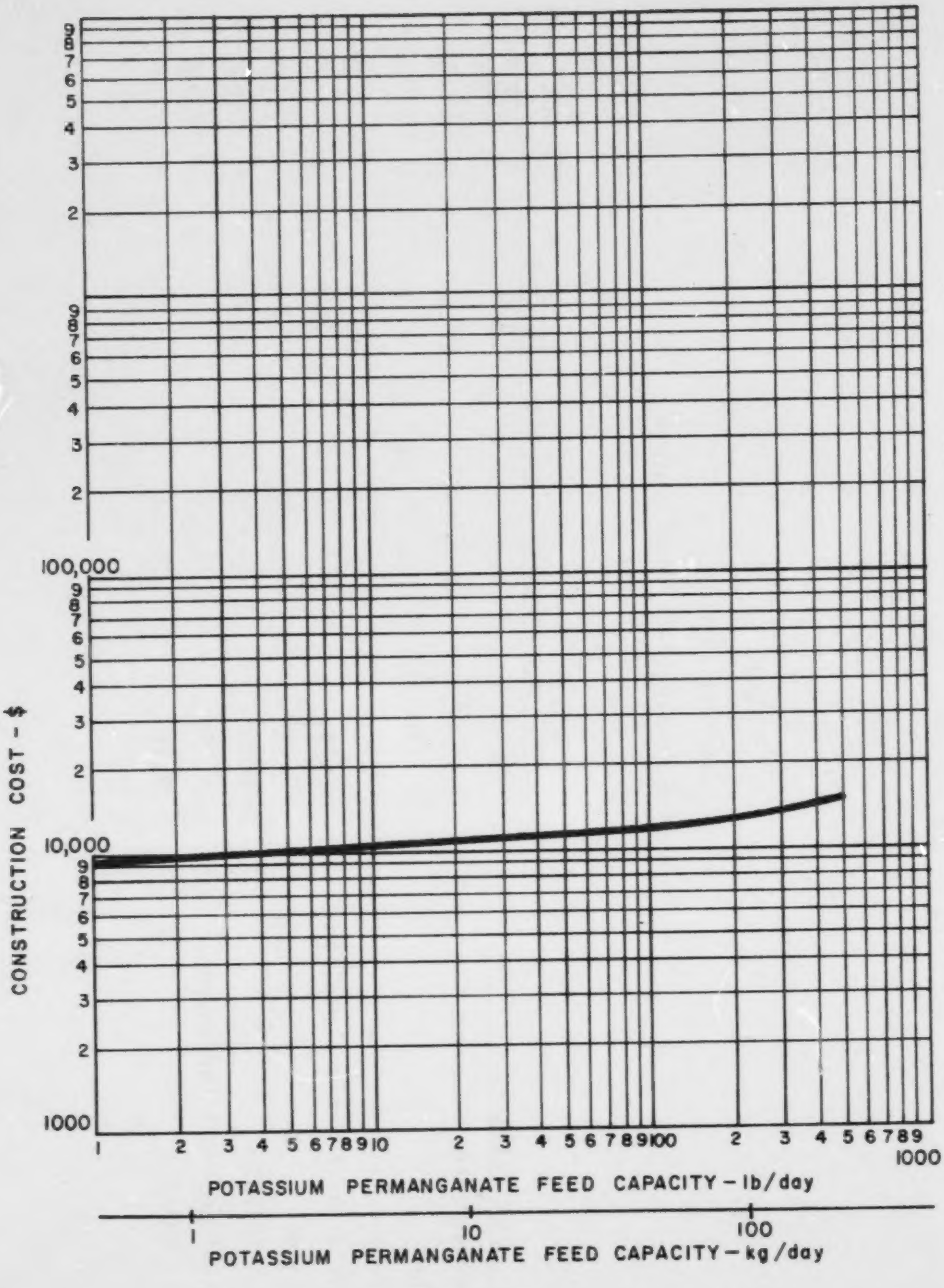


Figure 27. Construction cost for potassium permanganate feed systems.

Operation and Maintenance Cost

Process energy requirements are for the solution mixers and the metering pumps. Annual maintenance material costs were calculated at 3 percent of the cost of manufactured equipment.

Labor requirements are for unloading drums of chemicals, preparation of the 4 percent solution, and routine operation of the solution metering pump. One hour per day was used to prepare the 4 percent solution (0.1 hr/day for the 0.4 percent solution). Routine inspection and adjustment of the metering pumps is 15 min per shift, and maintenance requirements were 8 hr/year.

Figures 28 and 29 present the operation and maintenance requirements for potassium permanganate feed facilities. A summary of these requirements is presented in Table 20.

SULFURIC ACID FEED SYSTEMS

Construction Cost

Construction cost estimates were developed for sulfuric acid feed systems capable of metering concentrated (93 percent) sulfuric acid from a storage tank directly to the point of application. For sulfuric acid feed rates up to 200 gpd, the concentrated acid was assumed to be delivered to the plant site in drums, and at larger flow rates, it was assumed to be delivered in bulk. Acid purchased in bulk was assumed to be stored outdoors in FRP tanks, and acid purchased in drums was assumed to be stored indoors. Fifteen days of sulfuric acid storage was provided, and a standby metering pump was included for all installations except the smallest.

Estimated construction costs are presented in Table 21 and Figure 30.

Operation and Maintenance Cost

Process electrical energy requirements are for the metering pump. The increase in building energy requirements at the lower feed rates is attributable to the greater building area required for indoor storage of the sulfuric acid drums.

Maintenance material requirements were estimated at 3 percent of the equipment cost, excluding the cost of storage tanks.

Labor requirements are for chemical unloading and for the metering pumps. Unloading times of 0.25 hr/drum of acid and 1.5 hr/bulk truck delivery were utilized. Metering pump routine operation is 15 min/pump per day, and maintenance requirements are 8 hr/feeder per year.

Estimated operation and maintenance requirements are presented in Figures 31 and 32, and a summary of the requirements is presented in Table 22.

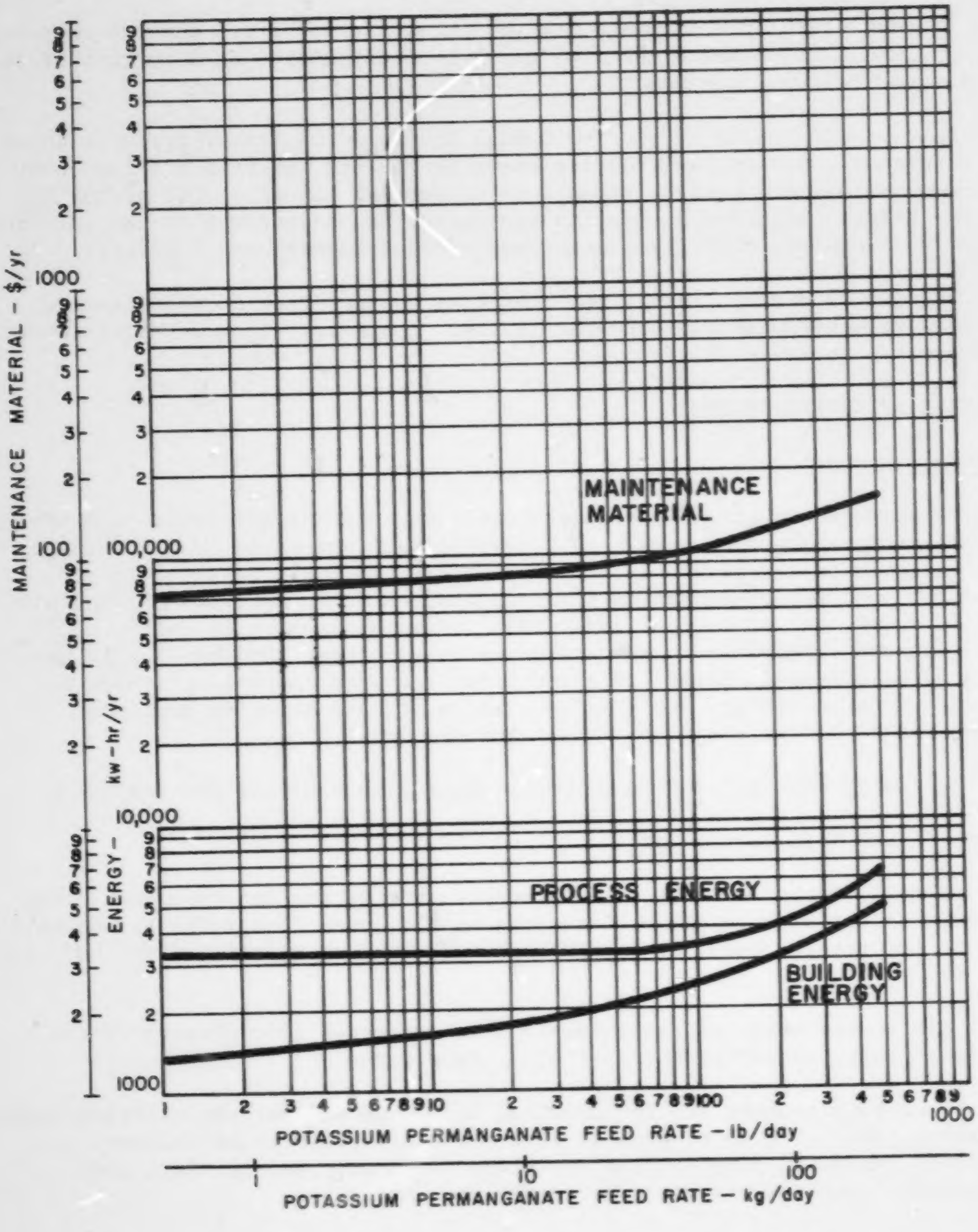


Figure 28. Operation and maintenance requirements for potassium permanganate feed systems - building energy, process energy and maintenance material.

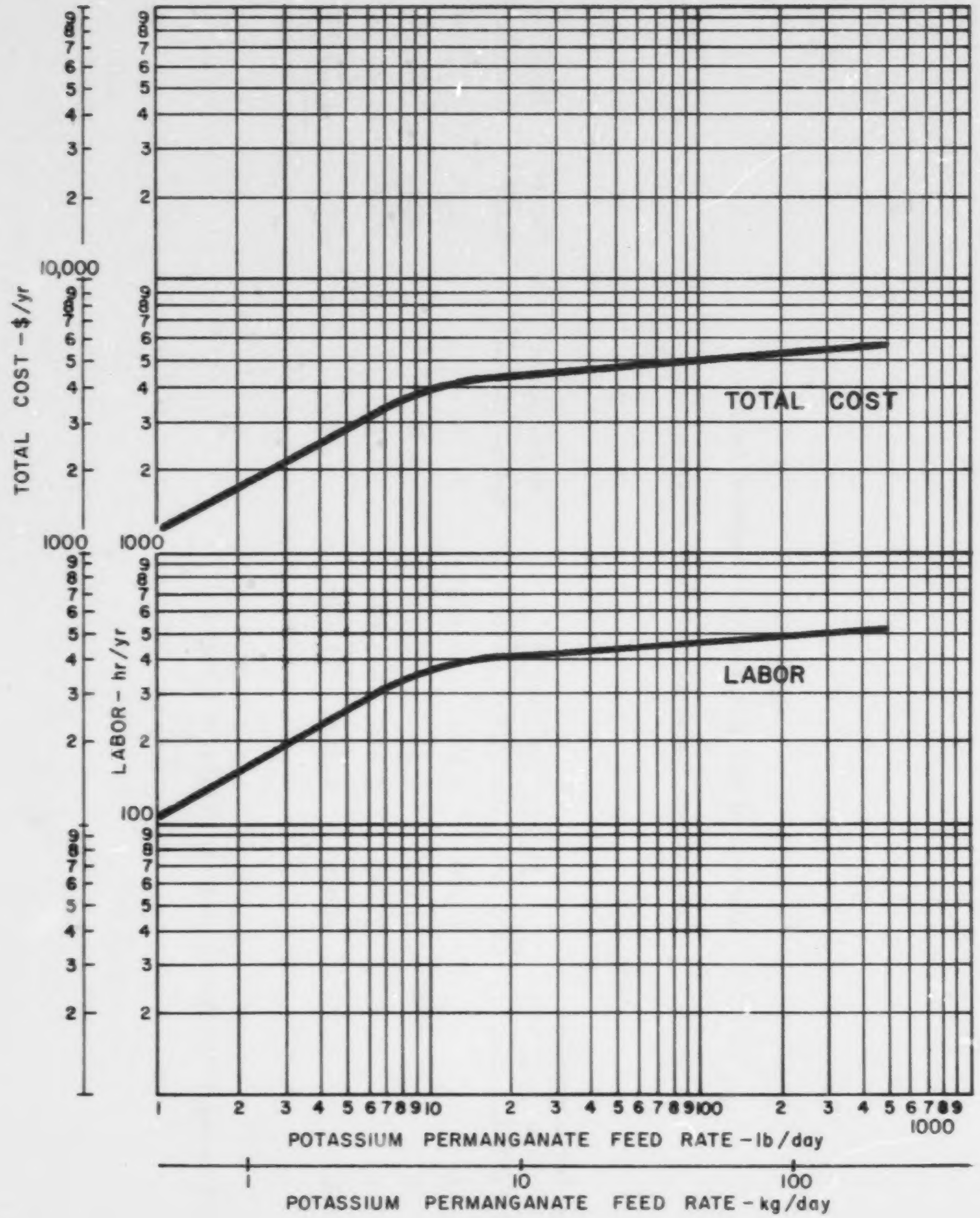


Figure 29. Operation and maintenance requirements for potassium permanganate feed systems - labor and total cost.

Table 20

Operation and Maintenance Summary for

Potassium Permanganate Feed Systems

Potassium Permanganate Feed Rate (lb/day)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
1	1,390	3,270	4,660	$ 70	101	$ 1,220
10	1,730	3,270	5,000	80	436	4,590
100	2,770	3,270	6,040	100	443	4,710
500	4,850	6,530	11,380	160	504	5,540

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 21

Construction Cost for

Sulfuric Acid Feed Systems

	Feed Capacity (gpd)			
Cost Category	10	100	1,000	5,000
Manufactured Equipment	$1,560	$3,440	$12,400	$41,000
Labor	640	820	2,840	11,840
Pipe and Valves	1,090	1,090	2,150	2,150
Electrical & Instrumentation	1,670	2,920	2,920	2,920
Housing	2,520	1,560	1,560	1,560
SUBTOTAL	7,480	9,830	21,870	59,470
Miscellaneous & Contingency	1,120	1,470	3,280	8,920
TOTAL	8,600	11,300	25,150	68,390

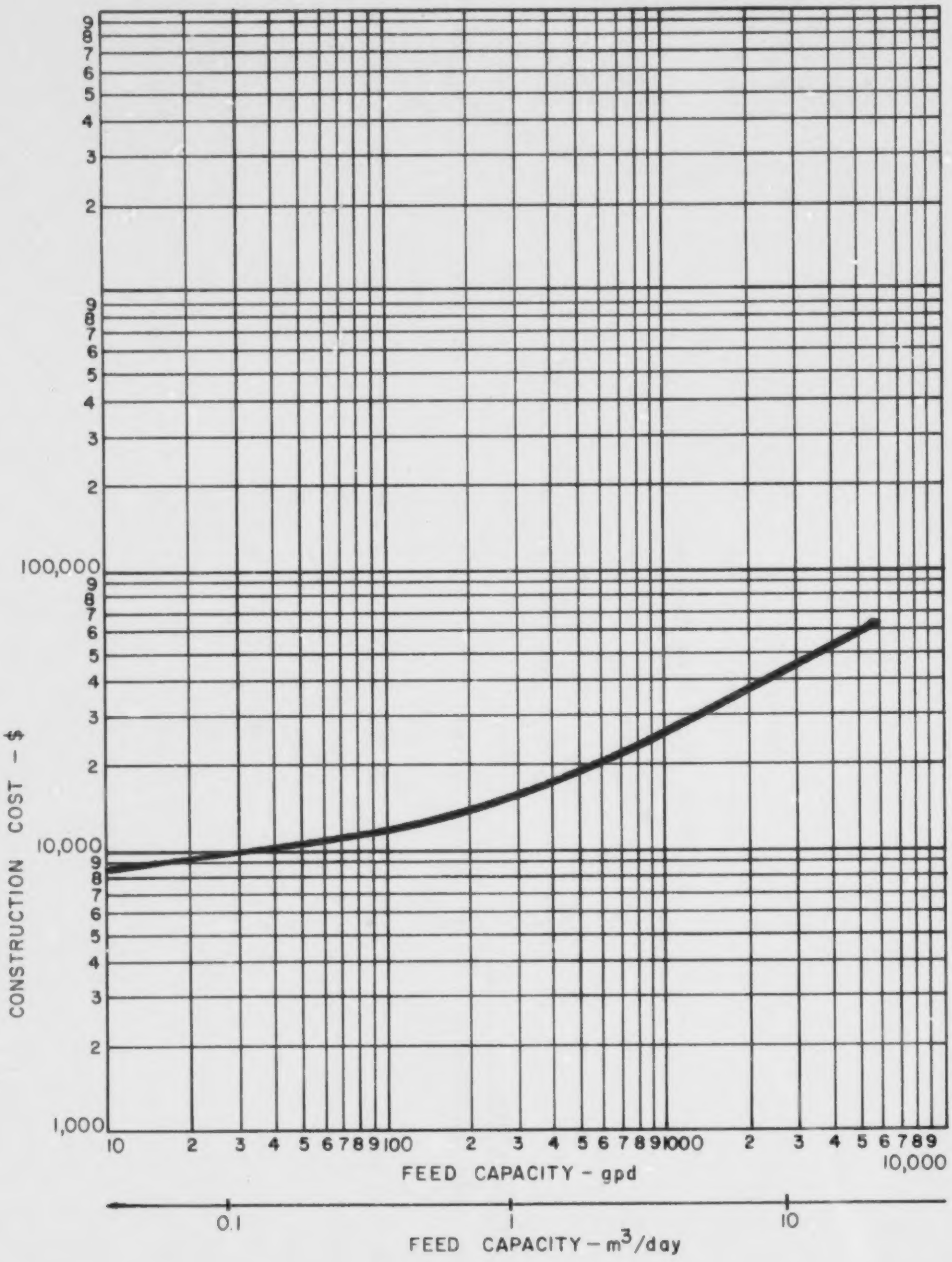


Figure 30. Construction cost for sulfuric acid feed systems.

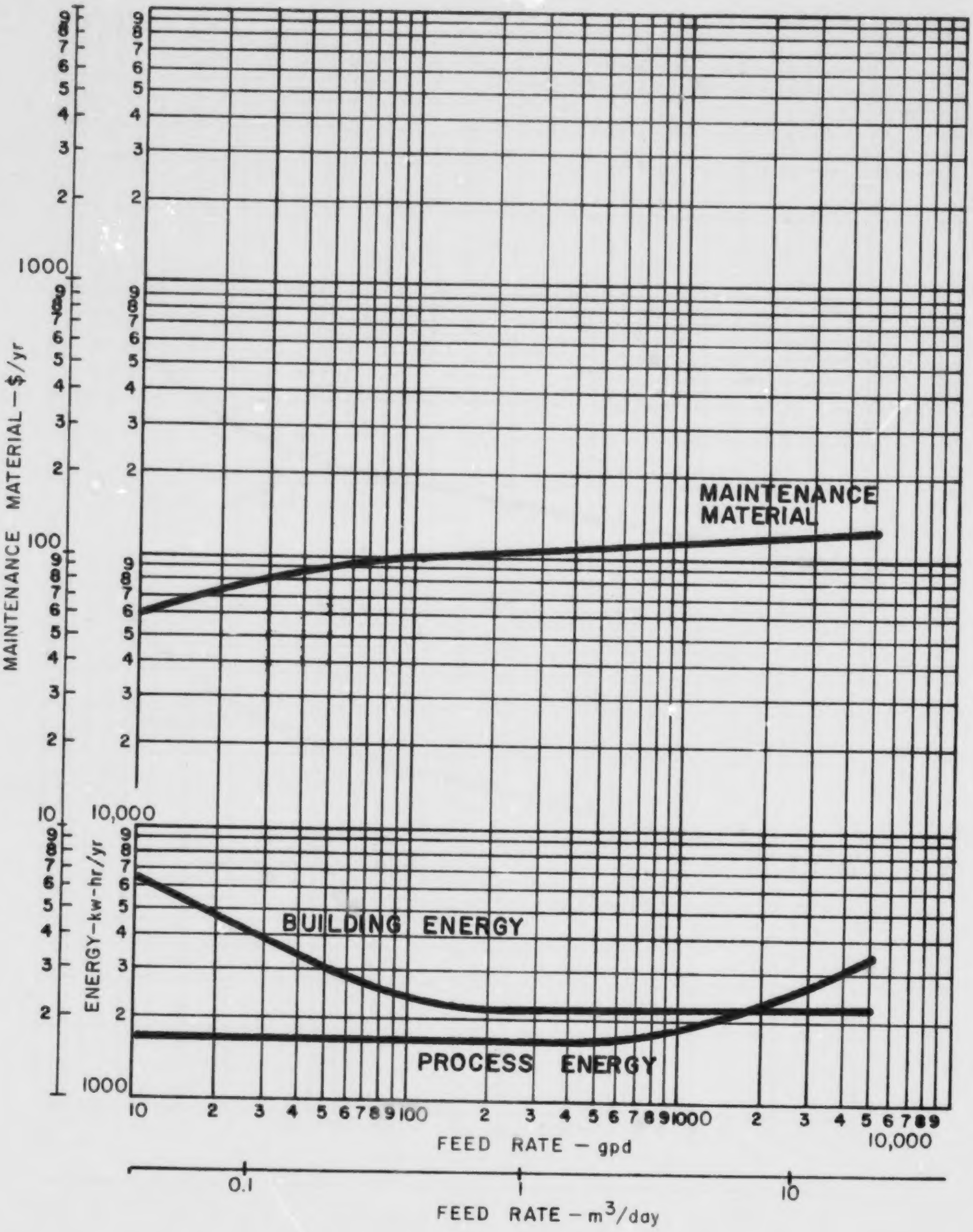


Figure 31. Operation and maintenance requirements for sulfuric acid feed systems - building energy, process energy and maintenance material.

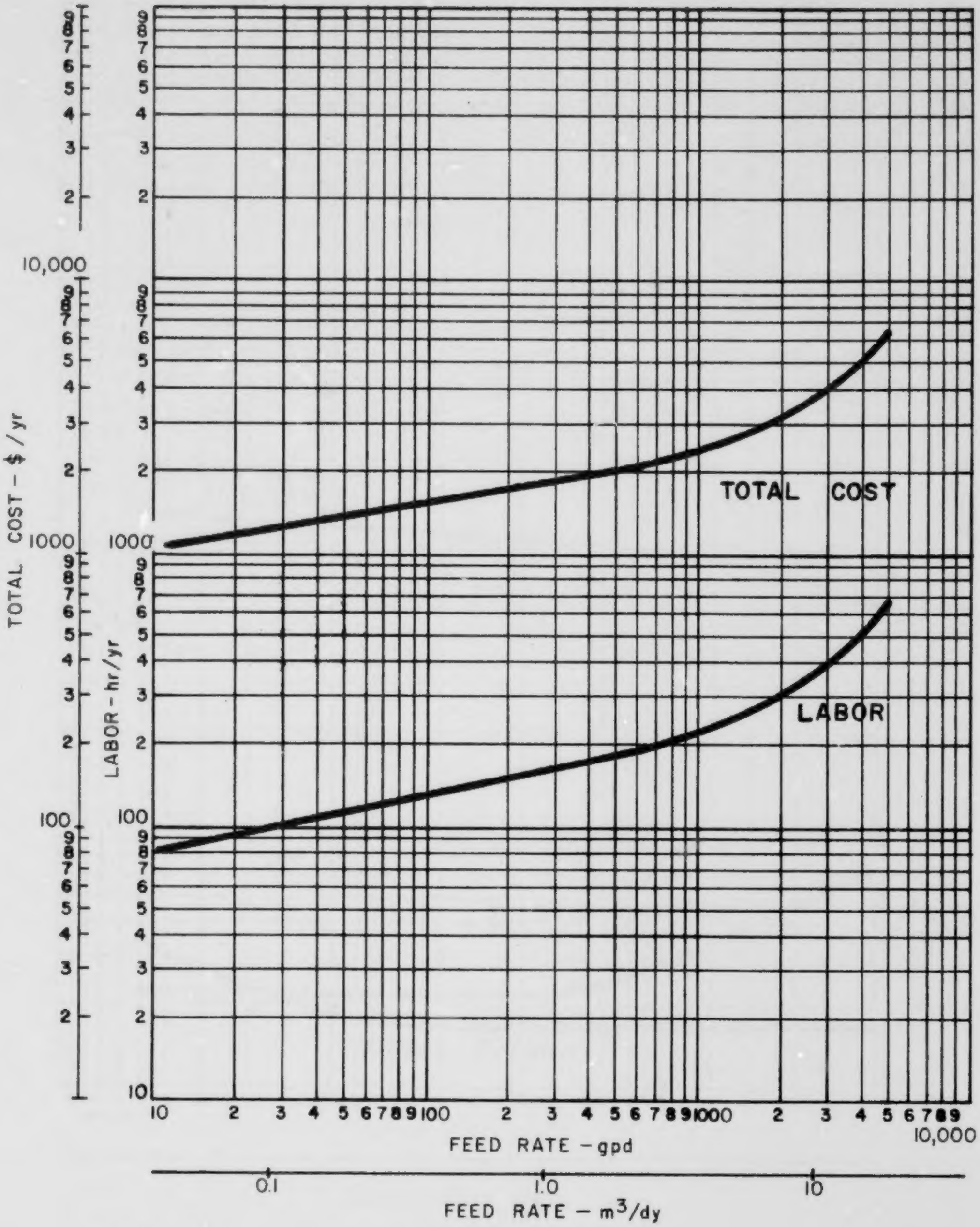


Figure 32. Operation and maintenance requirements for sulfuric acid feed systems - labor and total cost.

Table 22

Operation and Maintenance Summary for Sulfuric Acid Feed Systems

Sulfuric Acid Feed Rate (gpd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
10	6,160	1,630	7,790	$ 60	72	$ 1,010
100	2,050	1,630	3,680	100	154	1,750
1,000	2,050	1,630	3,680	120	200	2,230
5,000	2,050	3,270	5,320	130	613	6,420

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

SODIUM HYDROXIDE FEED SYSTEMS

Construction Cost

Costs were developed for sodium hydroxide feed rates between 10 and 10,000 lb/day. Dry sodium hydroxide was considered to be used at rates less than 200 lb/day, with liquid sodium hydroxide used at higher feed rates.

Dry sodium hydroxide (98.9 percent pure) is delivered to the plant site in drums and then mixed to a 10 percent solution on-site. A volumetric feeder is utilized to feed sodium hydroxide to the mixing tank. Two day tanks are necessary - one for mixing a 10 percent solution, and one for feeding. The use of two tanks is necessary because of the slow rate of sodium hydroxide addition necessary as a result of the high heat of solution. Each tank is equipped with a mixer, and a dual-head metering pump is used to convey the 10 percent solution to the point of application.

For feed rates greater than 200 lb/day, a 50 percent sodium hydroxide solution is purchased premixed and delivered by bulk transport. The 50 percent solution contains 6.38 lb of sodium hydroxide/gal. For the 50 percent solution, 15 days of storage was provided in FRP tanks. Dual-head metering pumps are used to convey solution to the point of application, and a standby metering pump was provided in each case.

Pipe and valving is required for water conveyance to the dry sodium hydroxide mixing tanks and between the metering pumps and the point of application. The storage tanks are located indoors, since 50 percent sodium hydroxide begins to crystallize at temperatures less than 54°F.

Estimated construction costs are shown in Figure 33 and on Table 23.

Operation and Maintenance Cost

Process energy requirements are for the volumetric feeder and mixer (smaller installations only) and the metering pump. A maintenance material requirement of 3 percent of equipment cost, excluding the storage tank cost, was utilized.

Labor requirements are based on unloading time for dry sodium hydroxide in drums, or the liquid 50 percent sodium hydroxide purchased in bulk for the larger installations. For installations using dry sodium hydroxide, additional labor is required for routine operation time for the volumetric feeder. This time is 10 min/day per feeder. In addition, for each installation, operation time for the dual head metering pump is 15 min/day, with an annual maintenance time of 8 hr.

Figures 34 and 35 show the operation and maintenance requirements for sodium hydroxide feed systems. A summary of these requirements is presented in Table 24.

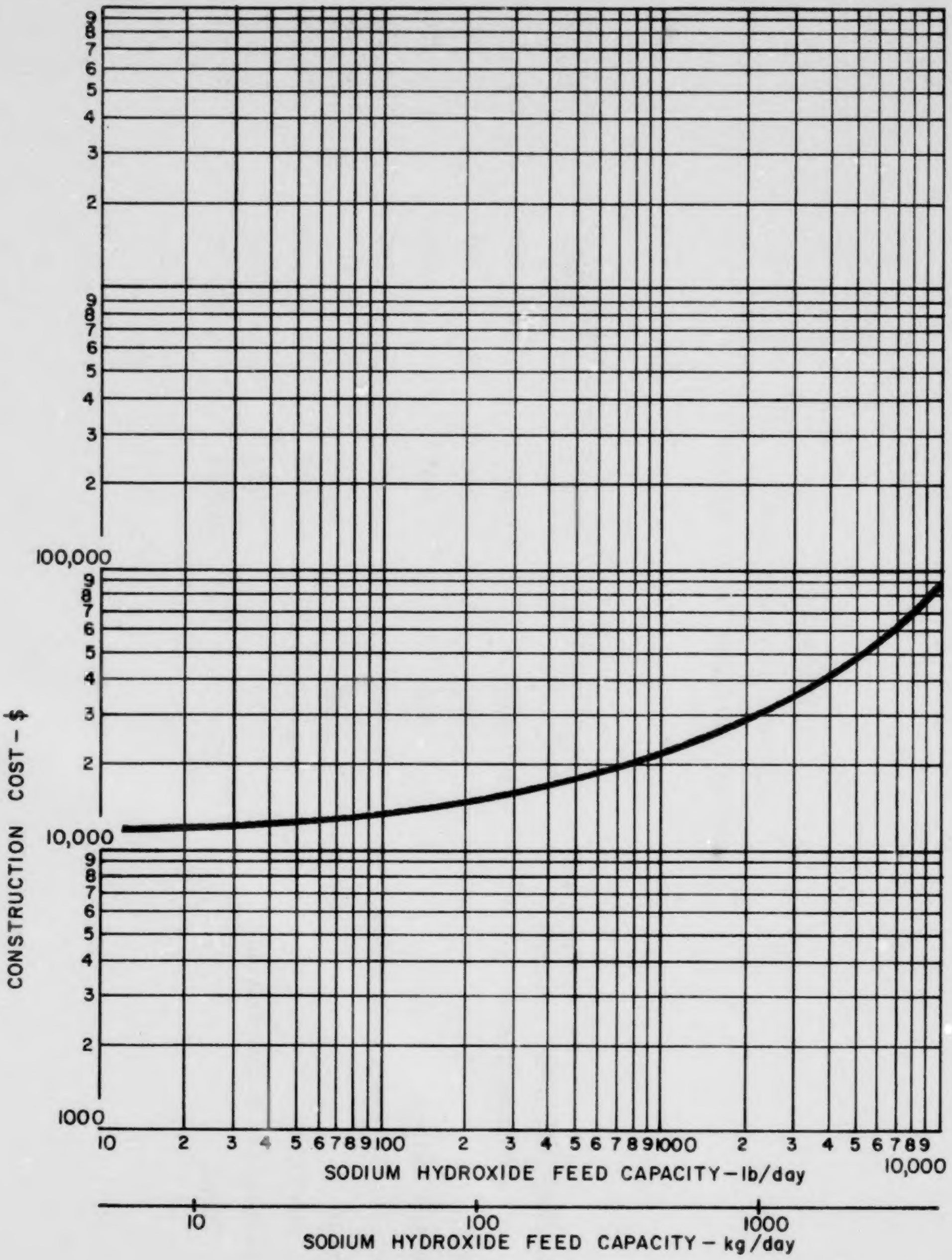


Figure 33. Construction cost for sodium hydroxide feed systems.

Table 23

Construction Cost for Sodium Hydroxide Feed Systems

Cost Category	Feed Capacity (lb/day)			
	10	100	1,000	10,000
Manufactured Equipment	$ 6,440	$ 7,010	$ 5,720	$ 19,450
Labor	640	640	790	4,120
Pipe and Valves	850	850	850	850
Electrical & Instrumentation	3,190	3,190	3,190	3,460
Housing	1,010	2,100	8,400	48,380
SUBTOTAL	12,130	13,790	18,950	76,260
Miscellaneous & Contingency	1,820	2,070	2,840	11,440
TOTAL	13,950	15,860	21,790	87,700

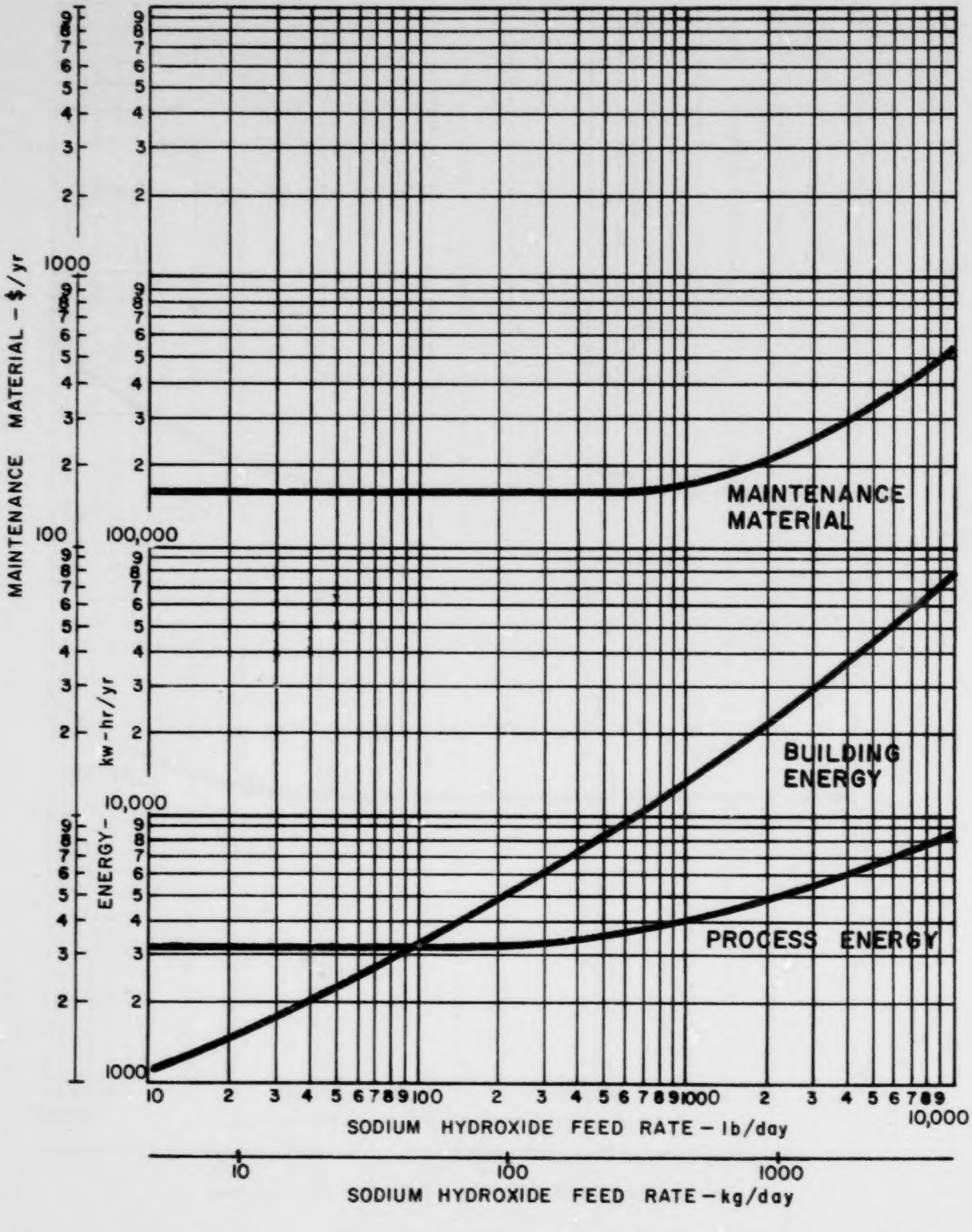


Figure 34. Operation and maintenance requirements for sodium hydroxide feed systems - building energy, process energy and maintenance material.

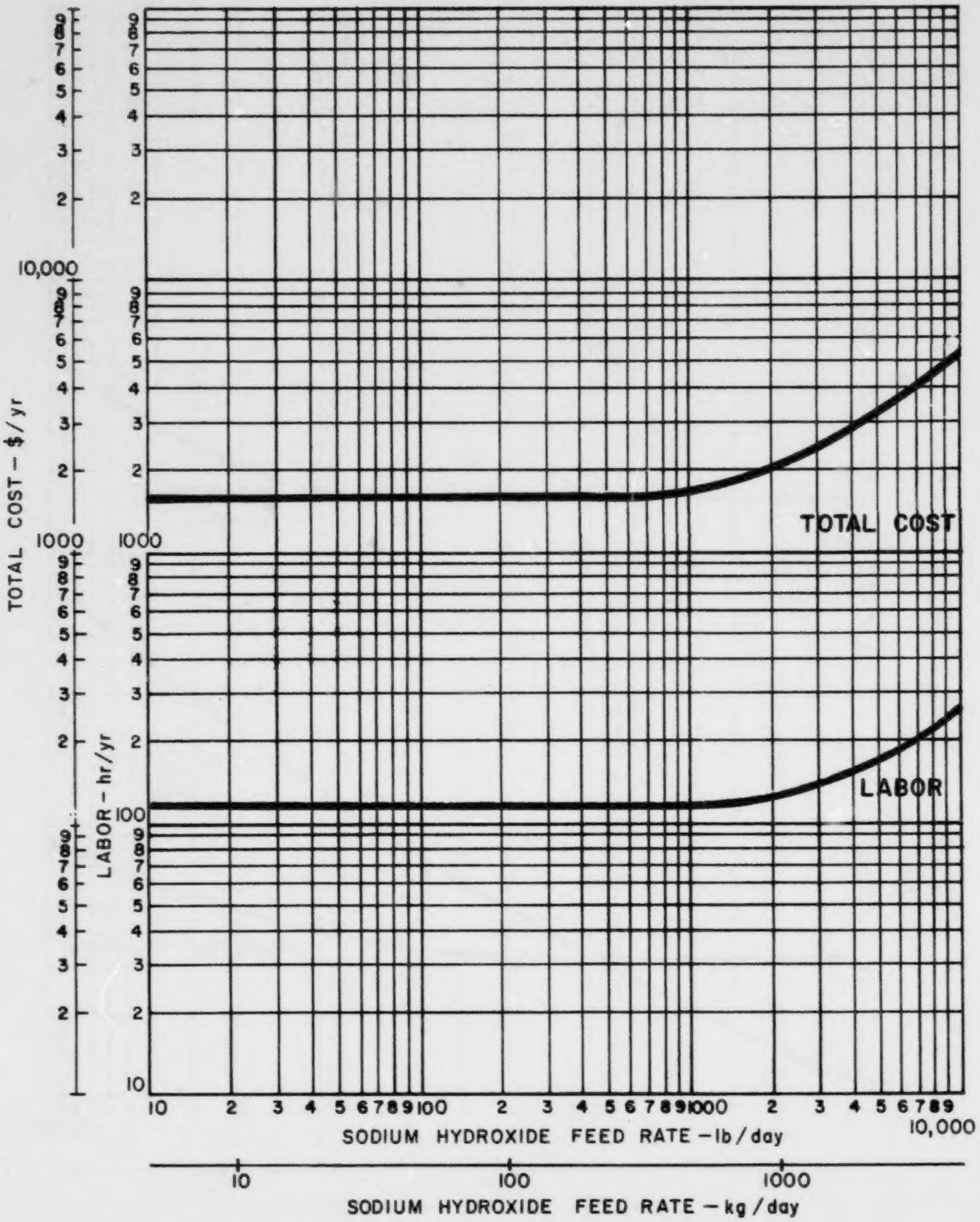


Figure 35. Operation and maintenance requirements for sodium hydroxide feed systems - labor and total cost.

Table 24

Operation and Maintenance Summary
for Sodium Hydroxide Feed Systems

Sodium Hydroxide Feed Rate (lb/day)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost*** ($/yr)
10*	1,110	3,270	4,380	$140	124	$1,510
100*	3,470	3,270	6,740	180	124	1,620
1,000**	13,860	4,900	18,760	120	85	1,530
10,000**	79,830	8,160	87,990	130	278	5,550

* Purchased as solid and mixed to a 10% solution on site

** Purchased as 50% solution

*** Calculated using $0.03/kw-hr and $10.00/hr of labor.

FERROUS SULFATE FEED SYSTEM

Construction Cost

Cost estimates for ferrous sulfate feed systems are based on use of $FeSO_4 \cdot 7H_2O$ with a density of 64 lb/ft^3. A 5-min detention period is required in the dissolving tank, and a 6 percent solution is fed to the point of application. Fifteen days of ferrous sulfate storage is included, using mild steel storage hoppers located indoors. Ferrous sulfate is conveyed pneumatically from bulk delivery trucks to the hoppers, with the blower located on the delivery truck. The largest hopper capacity utilized was 6,000 ft^3. For installations too small for bulk delivery, bag loaders are used on the feeder. All hopper facilities included dust collectors.

Volumetric feeders for the smaller installations and mechanical weigh belt feeders for the large installation and their respective solution tanks were located directly beneath the storage hoppers, eliminating the need for bucket elevators or other conveyance devices from below-ground storage. Such installation does, however, make the building cost somewhat greater than other possible arrangements. Conveyance from the solution tanks to the point of application was by dual-head diaphragm metering pumps.

Construction cost estimates for ferrous sulfate feed are presented in Table 25 and Figure 36.

Operation and Maintenance Cost

Electrical requirements are for solution mixers, feeder operation and building lighting, ventilation, and heating. Maintenance material costs were estimated on the basis of 3 percent of the manufactured equipment cost. Ferrous sulfate costs are not included in the maintenance material costs.

Labor requirements consist of chemical unloading and routine operation and maintenance of feeding equipment. Ferrous sulfate unloading requirements were calculated on the basis of 5 hr/50,000 lb. For installations using ferrous sulfate from bags, 8 hr were used/16,000 lb fed to the bag loader hopper. Time for routine inspection and adjustment of feeders is 10 min/feeder per shift. Maintenance requirements were 8 hr/year for liquid metering pumps and 24 hr/year for solid feeders and the solution tank.

Figures 37 and 38 present operation and maintenance requirements. A summary of operation and maintenance requirements is presented in Table 26.

FERRIC SULFATE FEED SYSTEMS

Construction Cost

Cost estimates for ferric sulfate feed facilities are based on use of $Fe_2(SO_4)_3 \cdot 3H_2O$ with a density of 80 lb/ft^3. A 20-min detention period is required in the dissolving tank, and a 20 to 25 percent solution is fed to the point of application. Fifteen days of storage is included, using mild

Table 25

Construction Cost for
Ferrous Sulfate Feed Systems

Cost Category	Feed Capacity (lb/hr) 10.7	107	1,070	5,350
Manufactured Equipment	$ 7,500	$13,100	$33,560	$160,940
Labor	420	1,130	2,430	12,160
Pipe and Valves	2,000	2,500	3,000	15,000
Electrical and Instrumentation	1,110	2,260	4,960	19,000
Housing	6,000	13,300	51,270	174,590
SUBTOTAL	17,030	32,290	95,220	381,690
Miscellaneous and Contingency	2,550	4,840	14,280	57,250
TOTAL	19,580	37,130	109,500	438,940

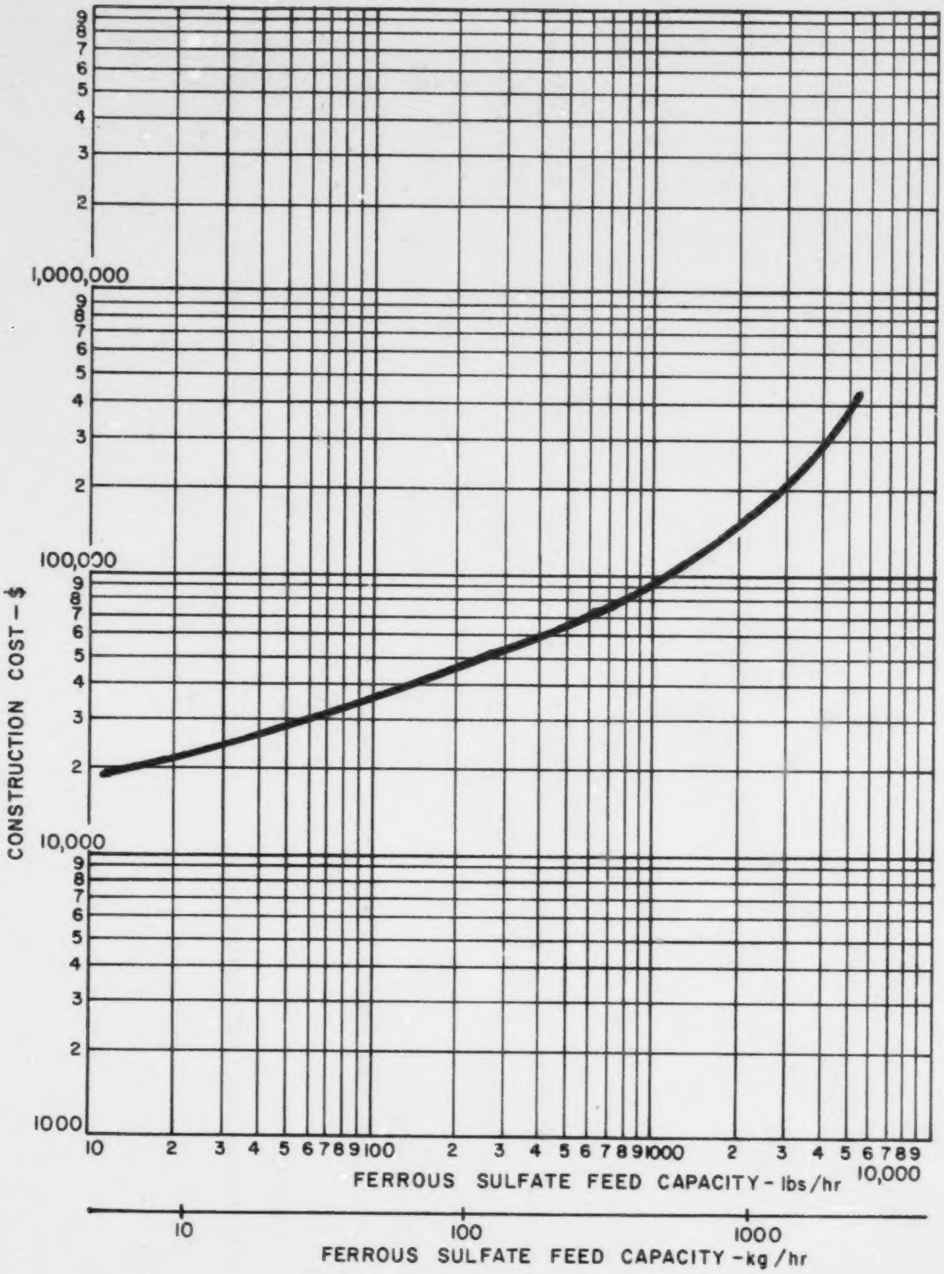


Figure 36. Construction cost for ferrous sulfate feed systems.

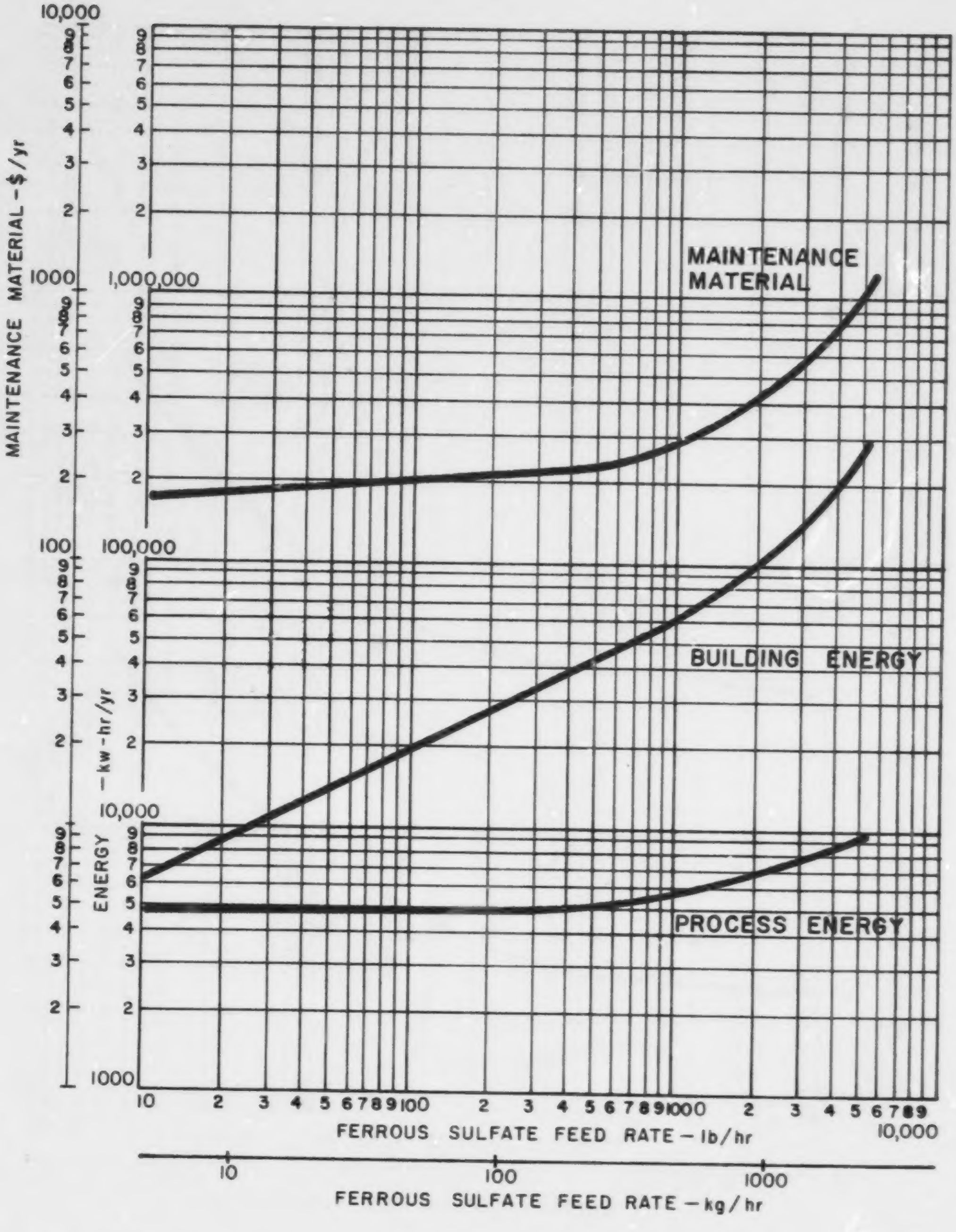


Figure 37. Operation and maintenance requirements for ferrous sulfate feed systems - building energy, process energy, and maintenance material.

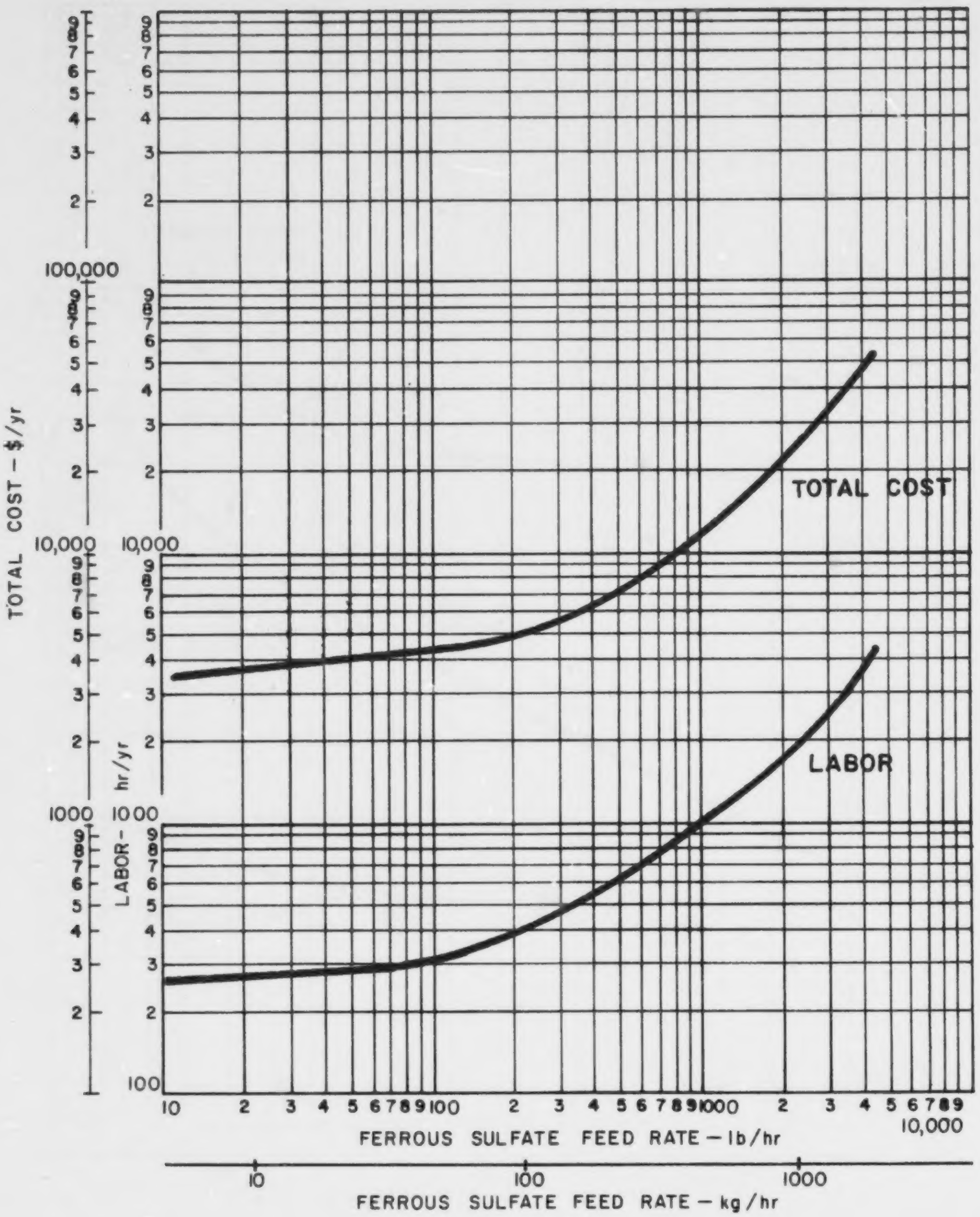


Figure 38. Operation and maintenance requirements for ferrous sulfate feed systems - labor and total cost.

Table 26

Operation and Maintenance Summary

for Ferrous Sulfate Feed Systems

Feed Rate (lb/hr)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
10.7	6,160	4,900	11,060	$ 180	288	$ 3,390
107	23,090	4,900	27,990	210	332	4,370
1,070	63,920	6,530	70,450	300	1,124	13,650
5,350	320,630	9,800	330,430	1,330	4,624	57,480

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

steel storage hoppers located indoors. Ferric sulfate is conveyed pneumatically from bulk delivery trucks to the hoppers, with the blower located on the delivery truck. The largest hopper capacity utilized was 6,000 ft^3, and all hopper facilities included dust collectors. For installations too small for bulk delivery, bag loaders are used on the feeder.

Volumetric feeders were used for all installations. The solution tank was located directly beneath the storage hoppers, thus eliminating the need for bucket elevators or other conveyance devices from below-ground storage. Such installation does, however, make the building cost somewhat greater than other possible arrangements. Conveyance from the solution tanks to the point of application was by dual-head diaphragm metering pumps.

Construction cost estimates for ferric sulfate feed are presented in Table 27 and Figure 39.

Operation and Maintenance Cost

Electrical requirements are for solution mixers, feeder operation, and building heating, lighting, and ventilation. Maintenance material costs were estimated on the basis of 3 percent of the manufactured equipment cost. Ferric sulfate costs are not included in the maintenance material costs.

Labor requirements consist of time for chemical unloading and routine operation and maintenance of feeding equipment. Ferric sulfate unloading requirements were calculated on the basis of 5 hr/50,000 lb. For installations using ferric sulfate from bags, 8 hr were used/16,000 lb fed to the bag loader hopper. Time for routine inspection and adjustment of feeders is 10 min/feeder per shift. Maintenance requirements were 8 hr/year for liquid metering pumps and 24 hr/year for solid feeders and the solution tank.

Figures 40 and 41 present operation and maintenance requirements. A summary of operation and maintenance requirements is presented in Table 28.

AMMONIA FEED FACILITIES

Construction Cost

A concept that may be used to provide disinfection without producing TTHM is the ammonia-chlorine process. Ammonia is added to water before chlorination, and chloramines are formed when chlorine is added. A chlorine/ammonia ratio of 3:1 is required to produce a combined chlorine residual that is mainly monochloramine.

Ammonia may be fed in either of two forms--anhydrous ammonia or aqua ammonia. Anhydrous ammonia is purchased as a pressurized liquid and is fed through evaporators and ammoniators and then as a gas to the point of application. Aqua ammonia is a solution of ammonia and water that contains 29.4 percent ammonia. Aqua ammonia is metered as a liquid directly to the point of application.

Table 27

Construction Cost for

Ferric Sulfate Feed Systems

Cost Category	Feed Capacity (lb/hr) 13.3	 133	 1,330	 6,600
Manufactured Equipment	$ 7,500	$ 13,100	$ 33,560	$ 160,940
Labor	420	1,130	2,430	12,160
Pipe and Valves	2,000	2,500	3,000	15,000
Electrical & Instrumentation	1,100	2,260	4,690	19,000
Housing	6,000	13,300	51,270	174,590
SUBTOTAL	17,020	32,290	94,950	381,690
Miscellaneous & Contingency	2,550	4,840	14,240	57,250
TOTAL	19,570	37,130	109,190	438,940

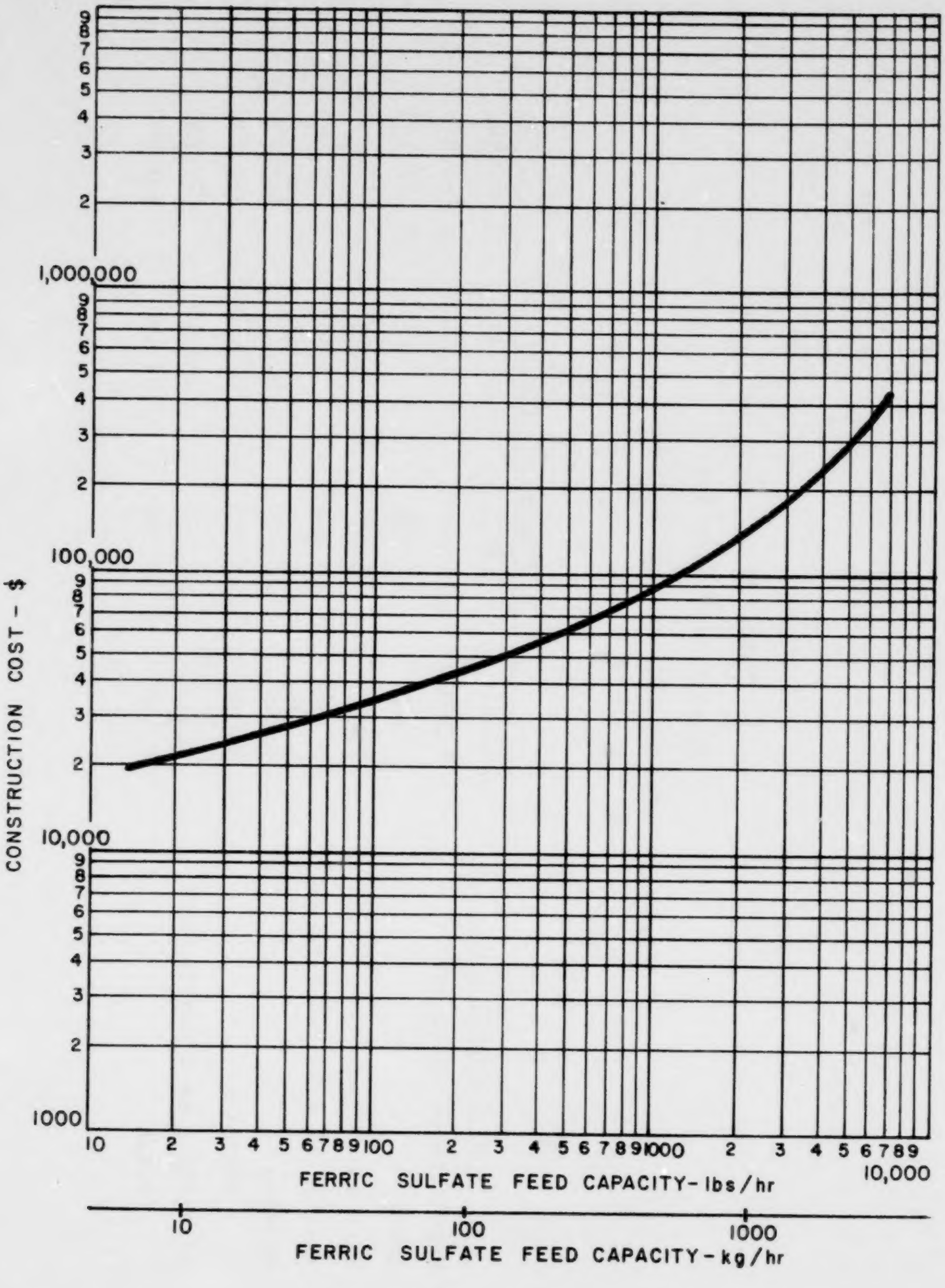


Figure 39. Construction cost for ferric sulfate feed systems.

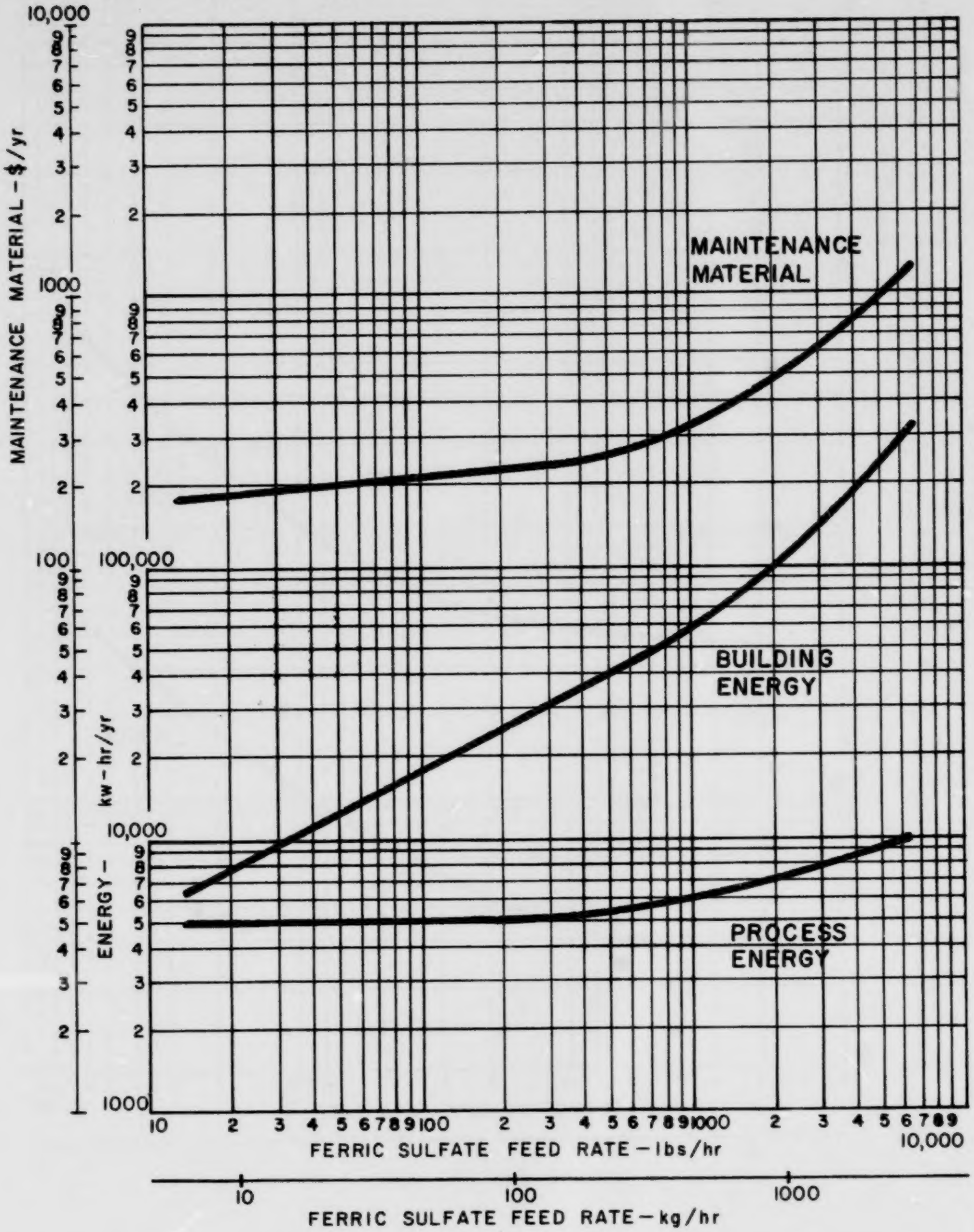


Figure 40. Operation and maintenance requirements for ferric sulfate feed systems - building energy, process energy, and maintenance material.

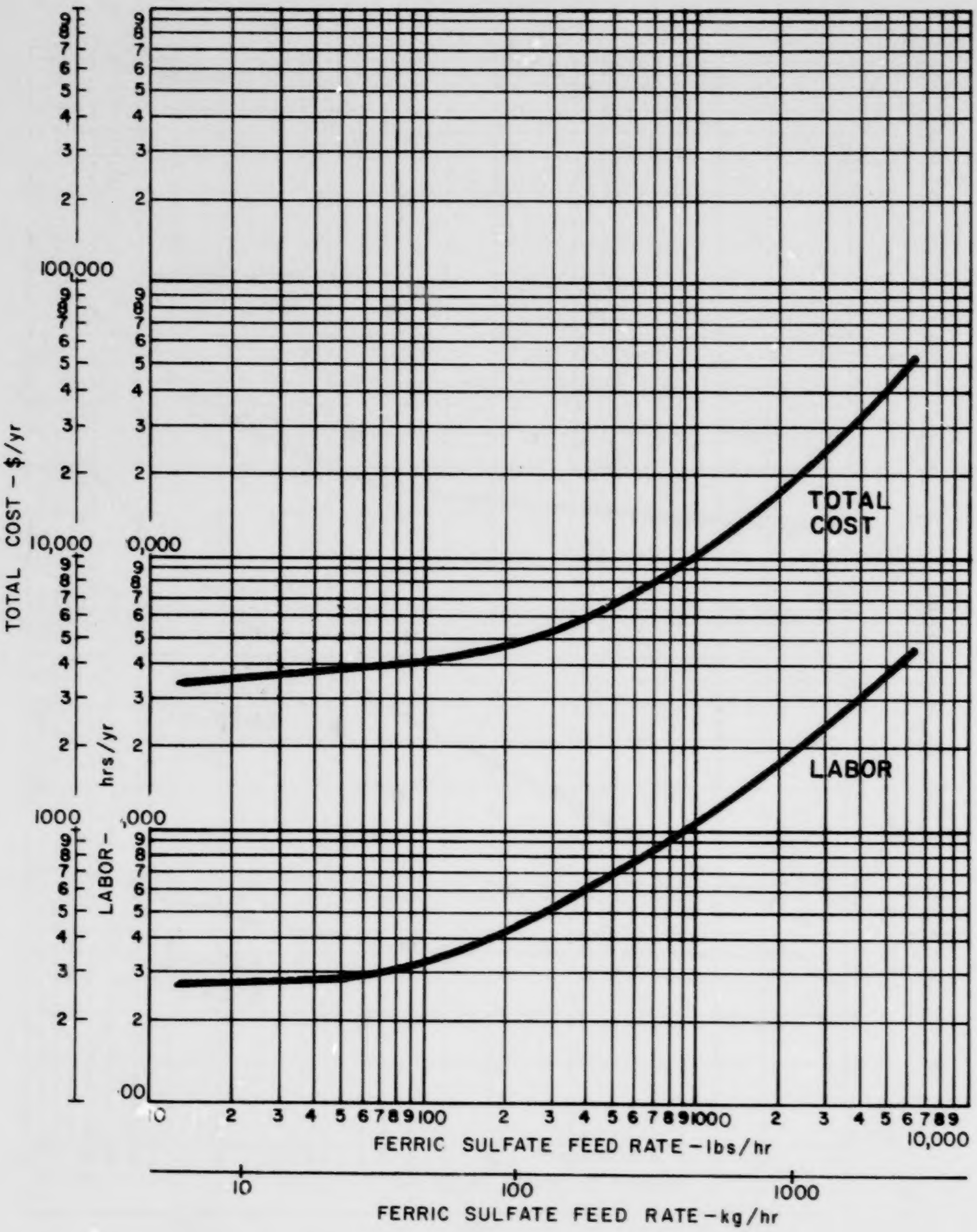


Figure 41. Operation and maintenance requirements for ferric sulfate feed systems - labor and total cost.

Table 28

Operation and Maintenance Summary for Ferric Sulfate Feed Systems

Feed Rate (lb/hr)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
13.3	6,160	4,900	11,060	$ 180	288	$ 3,390
133	23,090	4,900	27,990	210	332	4,370
1,330	63,920	6,530	70,450	300	1,124	13,650
6,660	320,630	9,800	330,430	1,330	4,624	57,480

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Generally speaking, aqua ammonia is readily available near large cities, and it is most commonly found in larger plants. A technical disadvantage of anhydrous ammonia can result if the gas produced by the ammoniator is used to produce a high-strength solution to be fed to the application point. In certain cases, magnesium precipitation occurs because of pH elevation that results from addition of the ammonia solution. In some cases, this severely restricts effective ammoniator capacity.

Construction cost curves include only ammonia storage and feed facilities. Separate curves are included in this report for chlorine feed systems.

Anhydrous Ammonia--

The cost curves include bulk ammonia storage for all feed rates, with 10 days of storage provided. The storage tanks include the tank and its supports, a scale, an air padding system, and all required gauges and switches. The ammonia feed system consists of an evaporator for flows in excess of 2,000 lb/day, an ammoniator, and flow-proportioning equipment. Dry ammonia gas was assumed to be fed directly to the point of application, rather than metering a high-strength ammonia solution to the point of application.

The construction cost curve for anhydrous ammonia feed facilities is presented in Figure 42, and a detailed breakdown of construction cost is shown in Table 29.

Aqua Ammonia--

Aqua ammonia is stored in a horizontal pressure vessel with a length/width ratio of approximately 3:1. Only one tank was used for each installation, and the assumed usable storage capacity was 10 days. Construction costs include the tank and its supports, required piping and valving for filling the tank from a bulk delivery truck and for conveying from the tank to the metering pump, and the metering pump. A housing cost is not included because only the metering pump is housed, and it could easily be located in a number of other housed areas.

The construction cost curve for aqua ammonia feed systems is presented in Figure 42 and a detailed breakdown is contained in Table 30.

Operation and Maintenance Cost

Anhydrous Ammonia Feed Facilities--

Electrical energy requirements are for heating, lighting, and ventilating of the ammoniator building, and operation of the evaporators. Evaporators are only included for systems of 2,000 lb/day or greater, and evaporator energy requirements were calculated on the basis of 23.8 kw-hr/ton of ammonia.

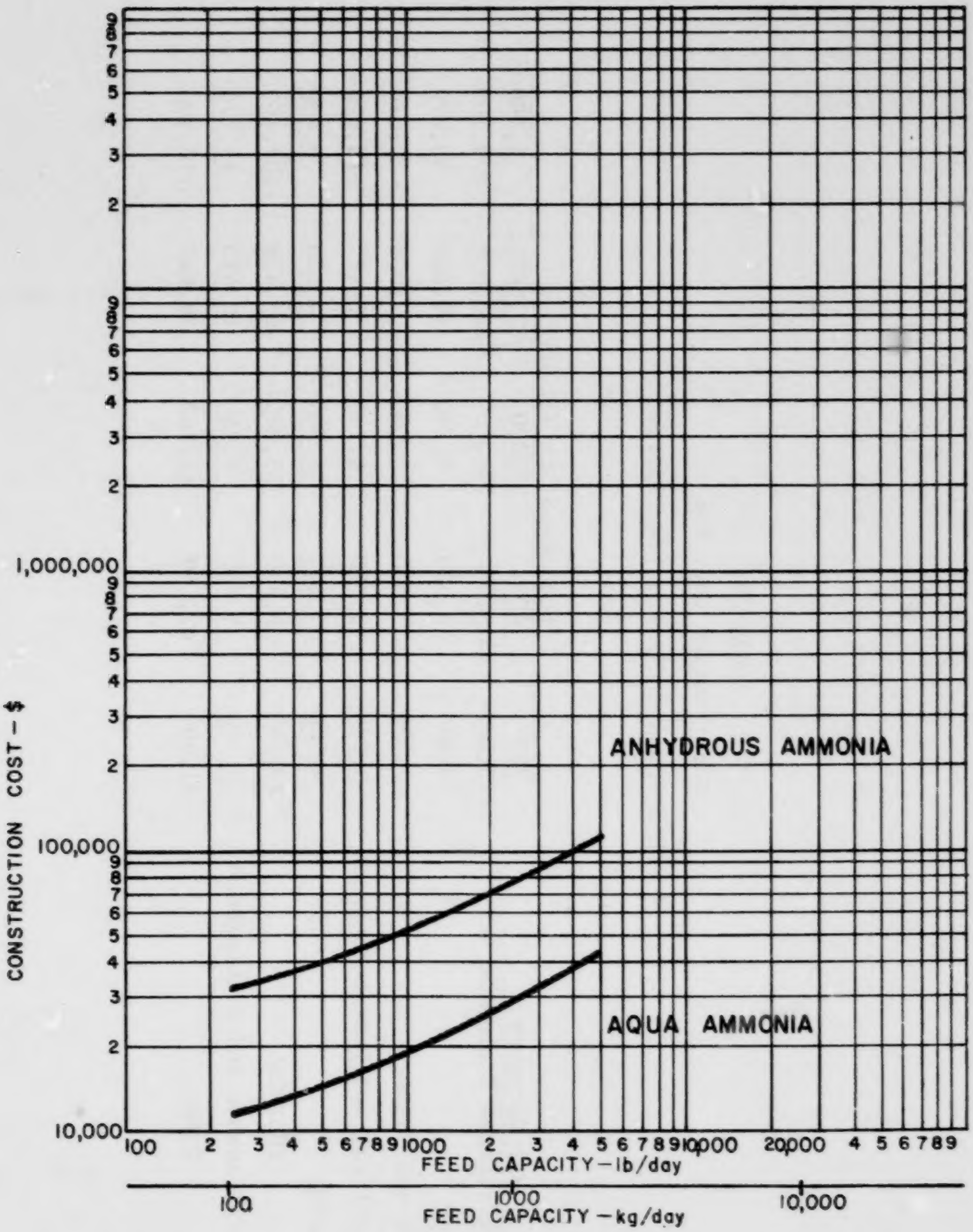


Figure 42. Construction cost for ammonia feed facilities.

Table 29

Construction Cost for
Anhydrous Ammonia Feed Facilities

Cost Category	Feed Capacity (lb/day) 250	500	1,000	2,500	5,000
Manufactured Equipment	$13,260	$19,520	$30,450	$38,830	$59.200
Labor	3,990	5,680	9,250	10,620	13,870
Pipe and Valves	2,390	3,520	5,500	7,000	10,670
Electrical and Instrumentation	3,250	3,770	6,180	8,480	10,990
Housing	4,500	4,500	4,500	4,500	6,430
SUBTOTAL	27,390	36,990	55,880	69,430	101,160
Miscellaneous and Contingency	4,110	5,550	8,380	10,410	15,170
TOTAL	31,500	42,540	64,260	79,840	116,330

Table 30

Construction Cost for

Aqua Ammonia Feed Facilities

Cost Category	Feed Capacity (lb/day)				
	250	500	1,000	2,500	5,000
Manufactured Equipment	$ 8,090	$ 10,430	$ 13,480	$ 19,340	$ 28,340
Labor	1,010	1,020	1,190	1,280	1,430
Pipe and Valves	670	670	910	1,690	1,690
Electrical and Instrumentation	1,050	2,510	2,930	5,230	7,540
SUBTOTAL	10,820	14,630	18,510	27,540	39,000
Miscellaneous and Contingency	1,620	2,190	2,780	4,130	5,850
TOTAL	12,440	16,820	21,290	31,670	44,850

Maintenance material requirements were based on operating experience at chlorination facilities of similar size. Anhydrous ammonia costs are not included in the maintenance material costs.

Labor requirements are for transfer of the bulk anhydrous ammonia from the delivery truck or rail car to the on-site ammonia storage tank, plus day-to-day operation and maintenance requirements. A bulk unloading time of 3 hr/shipment was utilized. Operation and maintenance requirements varied from roughly 1.5 hr/day for the smaller systems to 3 hr/day for larger systems.

Figures 43 and 44 present the operation and maintenance curves, and Table 31 presents a summary of the operation and maintenance requirements.

Aqua Ammonia Feed Facilities--

Electrical energy costs are only for operation of the metering pump. Because of the small indoor area required for the metering pump and standby pump, no allowance is included for building heating, lighting, and ventilation. Transfer of aqua ammonia from the bulk truck to the storage tank was assumed to be by a pump located on the bulk truck.

Maintenance material costs are for repair parts for the metering pump, valve repair, and painting of the storage tank. Aqua ammonia costs are not included in the maintenance material costs.

Labor costs include 15 min/day for operational labor, 24 hr/year for maintenance labor, and 1 hr/unloading of the bulk delivery truck.

Operation and maintenance requirements are presented in Figures 45 and 46 and summarized in Table 32.

POWDERED ACTIVATED CARBON FEED SYSTEMS

Construction Cost

The systems were sized for feeding of an 11-percent slurry (1 percent carbon/gal of water). The 11-percent slurry is stored and continuously mixed in uncovered concrete tanks, which are placed below ground level, except for approximately the top foot. For feed capacities of less than 700 lb/hr, 8 days of storage in two equal sized basins is included. For greater feed rates, 2 days of storage in a single basin is included. Mixers were sized based on a G value equal to 600. Storage/mixing basins include equipment for powdered activated carbon feed from bags in smaller installations and from trucks or railroad cars in larger installations.

For feed rates of less than 20 lb carbon/hr, a diaphragm type metering pump is used to feed directly from the mixing/storage tank to the point of application. For rates greater than 20 lb/hr, a positive displacement-type pump is used to transfer slurry continuously to an overhead rotodip volumetric feeder that feeds directly to the point of application.

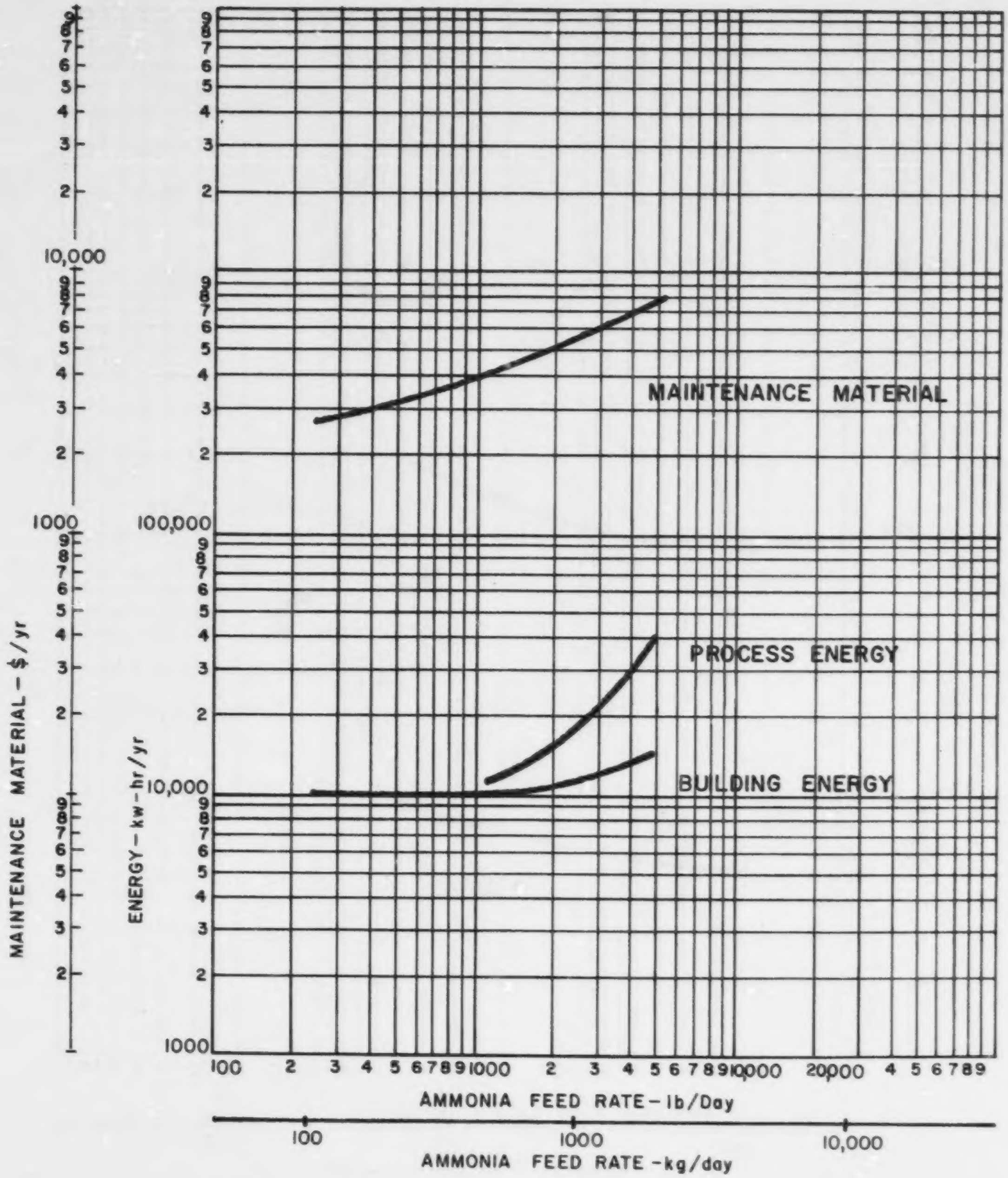


Figure 43. Operation and maintenance requirements for anhydrous ammonia feed facilities - building energy, process energy, and maintenance material.

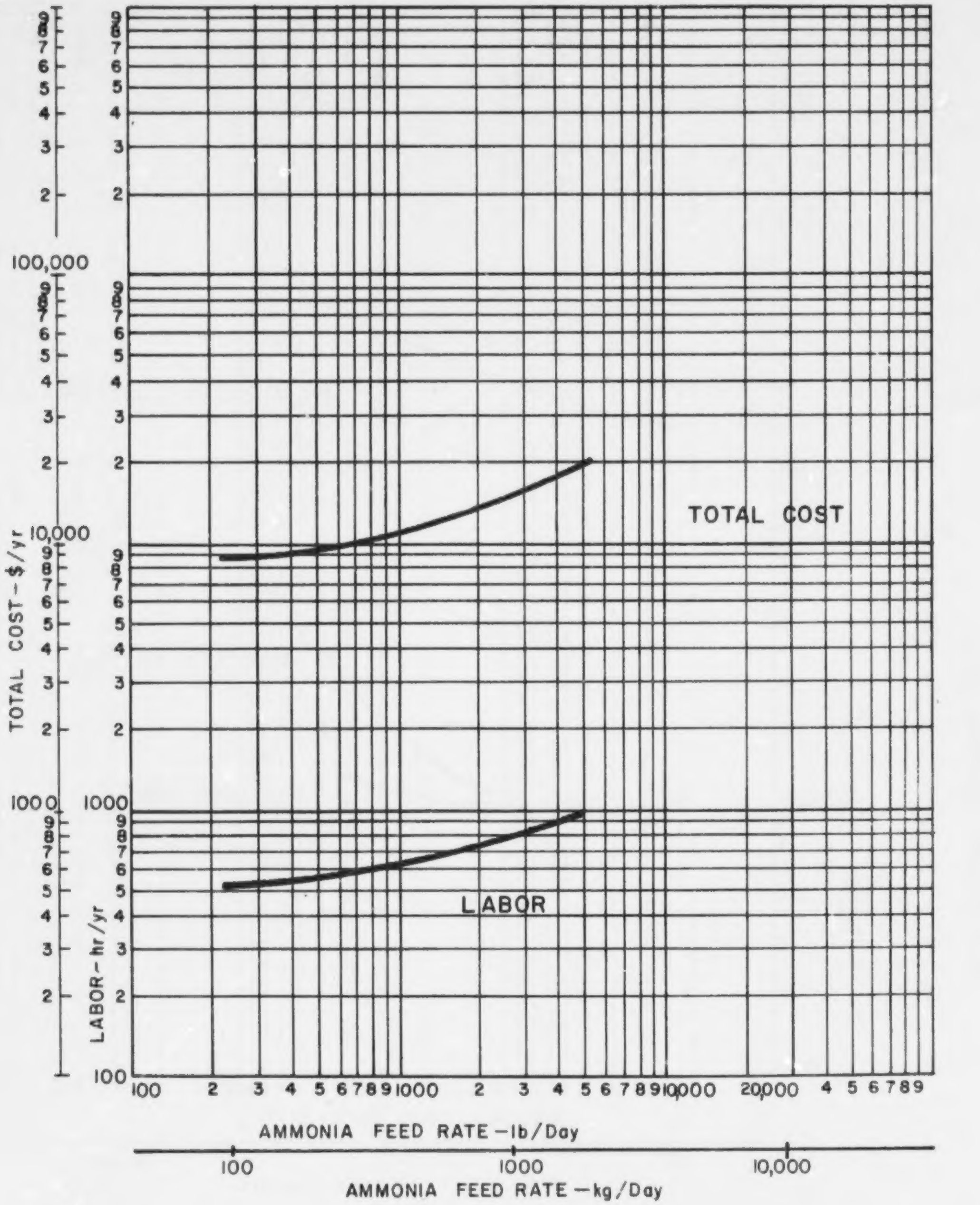


Figure 44. Operation and maintenance requirements for anhydrous ammonia feed facilities - labor and total cost.

Table 31

Operation and Maintenance Summary

for Anhydrous Ammonia Feed Facilities

Ammonia Feed Rate (lb/day)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
250	10,260	--	10,260	$ 3,060	500	$ 8,370
500	10,260	--	10,260	3,530	580	9,640
1,000	10,260	8,690	18,950	4,700	630	11,570
2,500	10,260	21,720	31,980	5,880	780	14,640
5,000	15,390	43,450	58,840	8,230	990	19,900

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

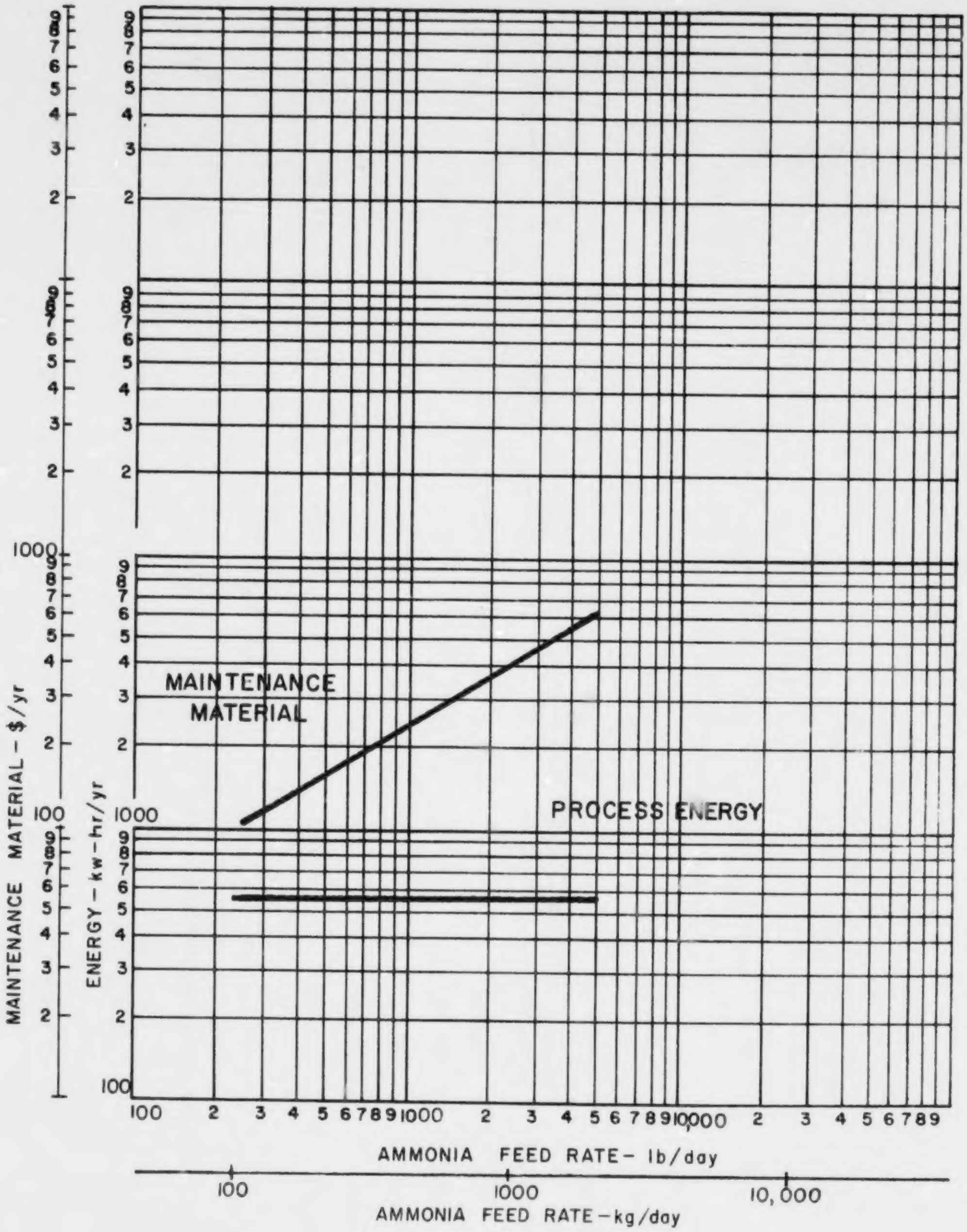


Figure 45. Operation and maintenance requirements for aqua ammonia feed facilities - process energy and maintenance material.

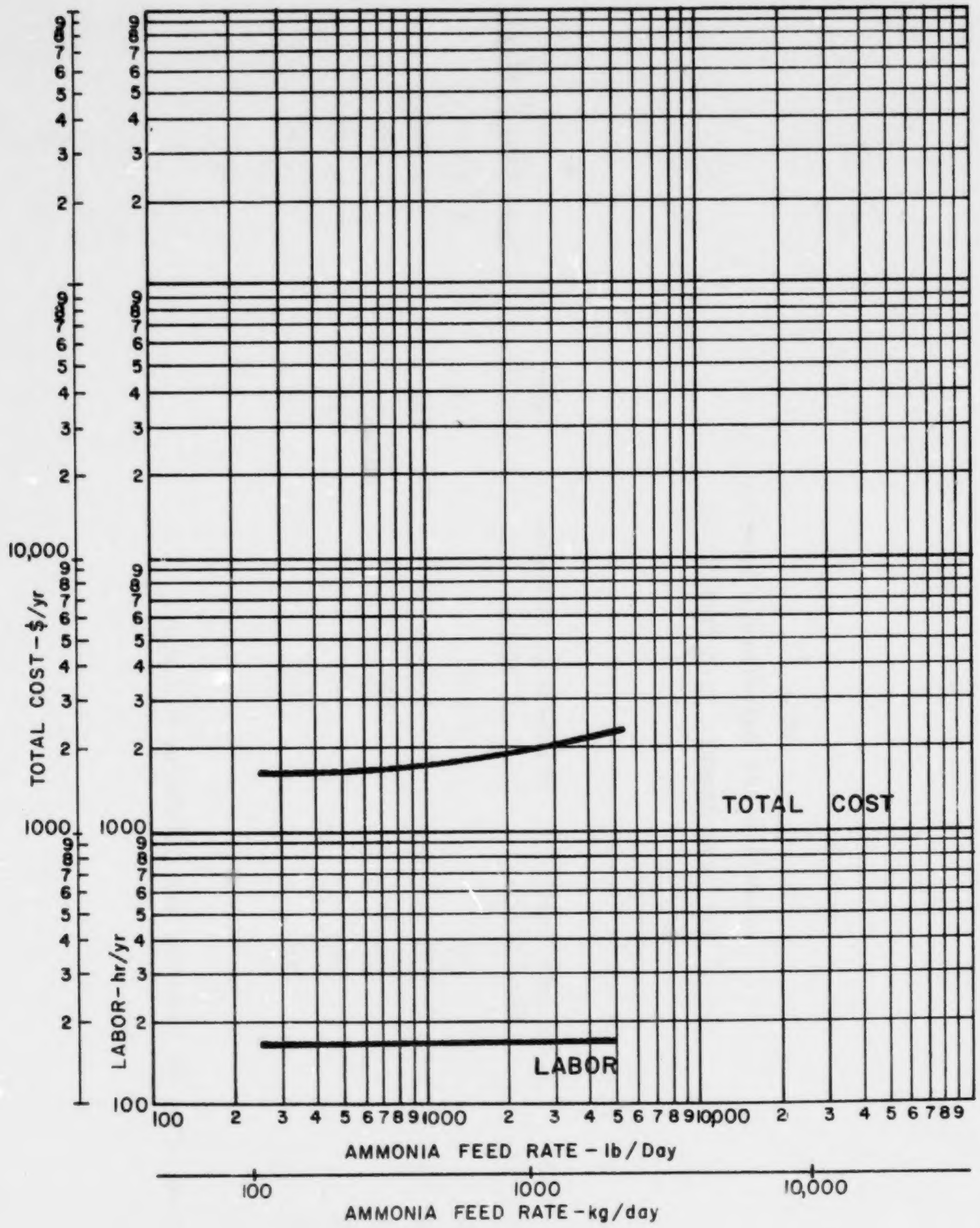


Figure 46. Operation and maintenance requirements for aqua ammonia feed facilities - labor and total cost.

Table 32
Operation and Maintenance Summary for Aqua Ammonia Feed Facilities

Ammonia Feed Rate (lb/day)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost ($/yr)*
250	570	$ 110	152	$ 1,650
500	570	160	152	1,700
1,000	570	270	152	1,810
2,500	570	430	152	1,970
5,000	570	640	152	2,180

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Construction cost is shown in Figure 47 and presented in detail in Table 33.

Operation and Maintenance Cost

Energy requirements are based on the rated horsepower of pump motors and continuous mixing of the 11-percent carbon slurry at a G value of 600.

Maintenance material requirements consist of oil for gearbox drives and for minor repair of pumps and motors, as well as the associated electrical switching gear.

Labor requirements for carbon unloading were based on rates of 10 min/50 lb bag, 2 hr/9,000 lb truckload, and 4 hr/27,000 lb railroad car. Requirements for the mixing/storage basin are 30 min/day per basin for inspection and routine maintenance, and 16 hr/year per basin for cleaning and gearbox oil change. Slurry pumps would require 1 manhour/day per pump.

Table 34 summarizes the operation and maintenance requirements, which are also shown in Figures 48 and 49.

RAPID MIX

Construction Cost

Construction costs were calculated for reinforced concrete basins, with total volumes ranging from 100 to 20,000 ft^3. The largest basin capacity utilized was 2,500 ft^3, and common wall construction was utilized when more than one basin was required. Mixer costs are for vertical shaft, variable speed turbine mixers with 304 stainless steel shafts and paddles and TEFC motors. Construction costs for G values of 300, 600, and 900 (3, 6, and 20 foot-pounds/second per ft^3, respectively) and a water temperature of 15°C are presented in Figure 50 and in Tables 35 to 37.

Operation and Maintenance Cost

Power requirements are a function of G and water temperature. At a water temperature of 15°C and G values of 300, 600, and 900, energy requirements were calculated on the basis of respective horsepower per unit volume requirements of 3, 6, and 20 foot-pounds/second per ft^3. An overall mechanism efficiency of 70 percent was utilized.

Maintenance material costs consist of oil for the gearbox drive unit.

Labor requirements were determined using a jar testing time of 1 hr/day for plants under 50 mgd and 2 hr/day for plants over 50 mgd, 15 min/mixer per day for routine operation and maintenance, and 4 hr/mixer per 6 months for oil changes. An allowance of 8 hr/basin per year was also included for draining, inspection, and cleaning.

Figures 51 and 52 show operation and maintenance curves for the rapid mix units, and a summary of these requirements is presented in Table 38.

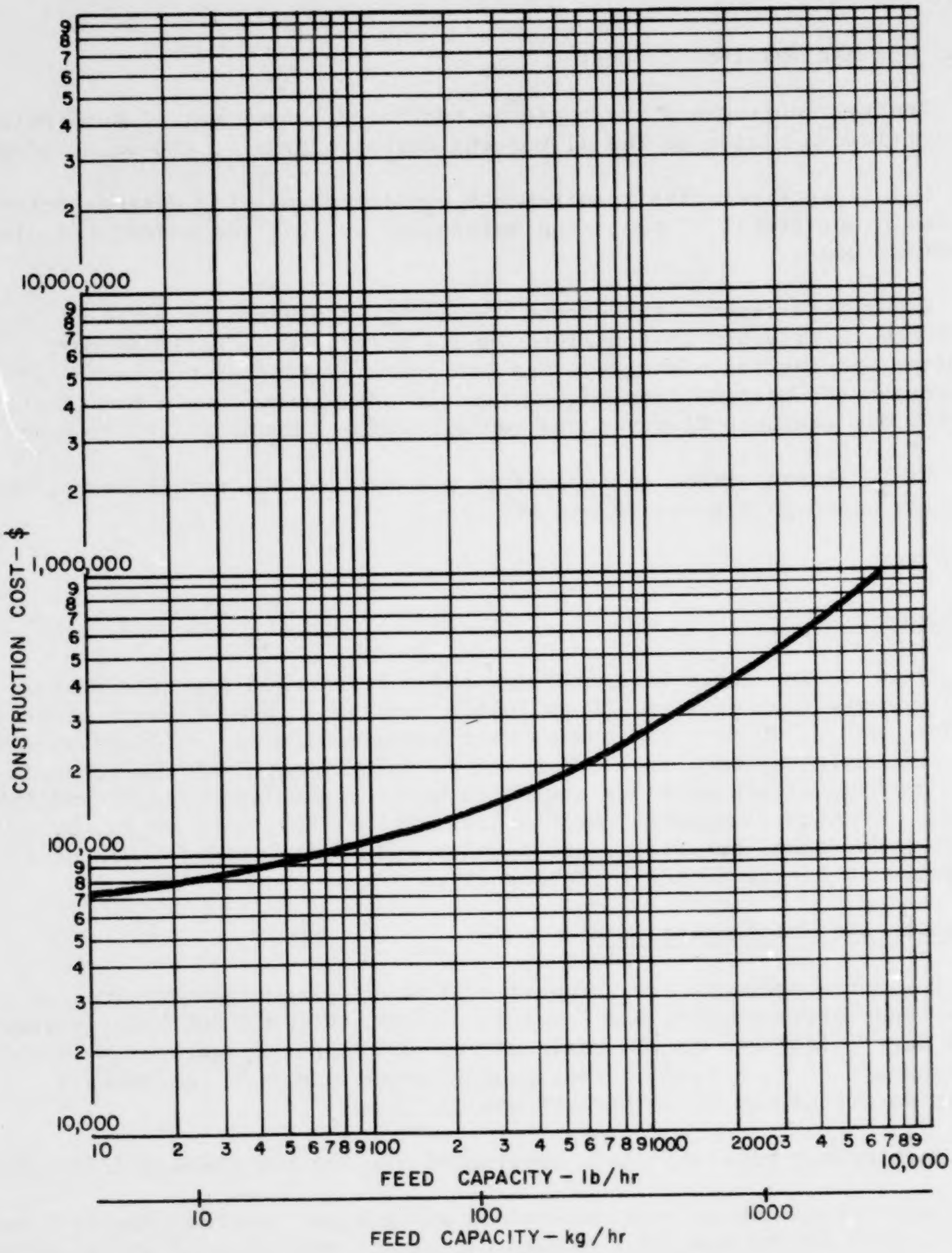


Figure 47. Construction cost for powdered activated carbon feed systems.

Table 33

Construction Cost for

Powdered Activated Carbon Feed Systems

Cost Category	Feed Capacity (lb/hr)				
	3.5	35	350	700	7,000
Excavation and Sitework	$ 90	$ 360	$ 1,480	$ 2,230	$ 11,140
Manufactured Equipment	8,680	22,490	70,450	126,040	537,490
Concrete	290	1,060	4,140	5,910	29,560
Steel	250	1,810	7,430	10,820	54,060
Labor	590	2,230	8,960	13,150	65,740
Pipe and Valves	18,240	18,550	18,910	19,750	89,660
Electrical and Instrumentation	23,540	24,410	26,100	52,950	114,930
Housing	6,430	6,430	6,430	6,430	6,430
SUBTOTAL	58,110	77,340	143,900	237,280	909,010
Miscellaneous and Contingency	8,720	11,600	21,580	35,590	136,350
TOTAL	66,830	88,940	165,480	272,870	1,045,360

Table 34

Operation and Maintenance Cost for Powdered Activated Carbon Feed Systems

Feed Rate (lb/hr)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
3.5	10,260	7,000	17,260	$ 2,140	850	$ 11,160
35	10,260	59,000	69,260	4,280	1,110	17,460
350	10,260	482,000	492,260	8,550	1,840	41,720
700	10,260	946,000	956,260	14,970	2,010	63,760
7,000	10,260	2,294,000	2,304,260	66,280	11,000	245,410

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

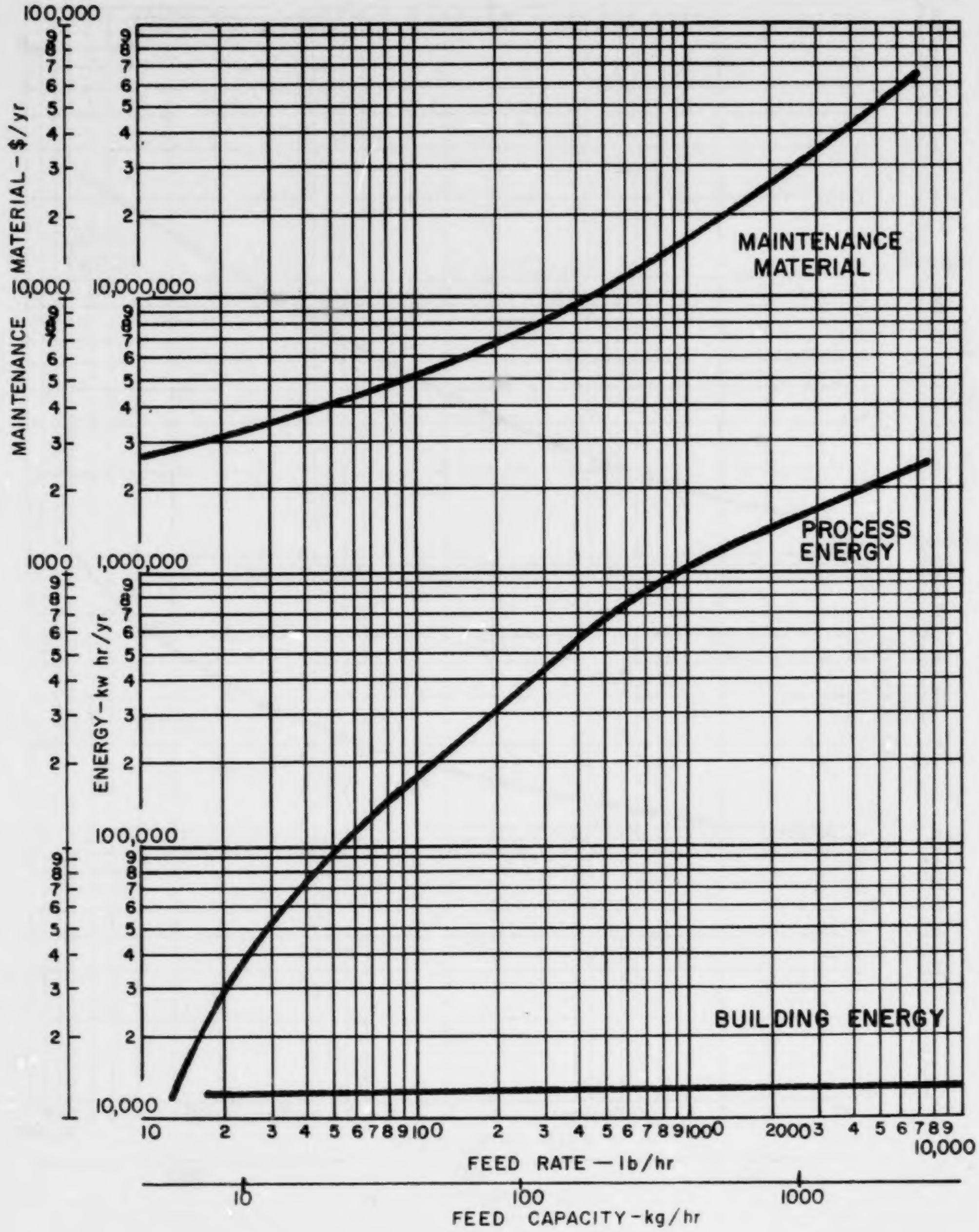


Figure 48. Operation and maintenance requirements for powdered activated carbon feed systems - building energy, process energy, and maintenance material.

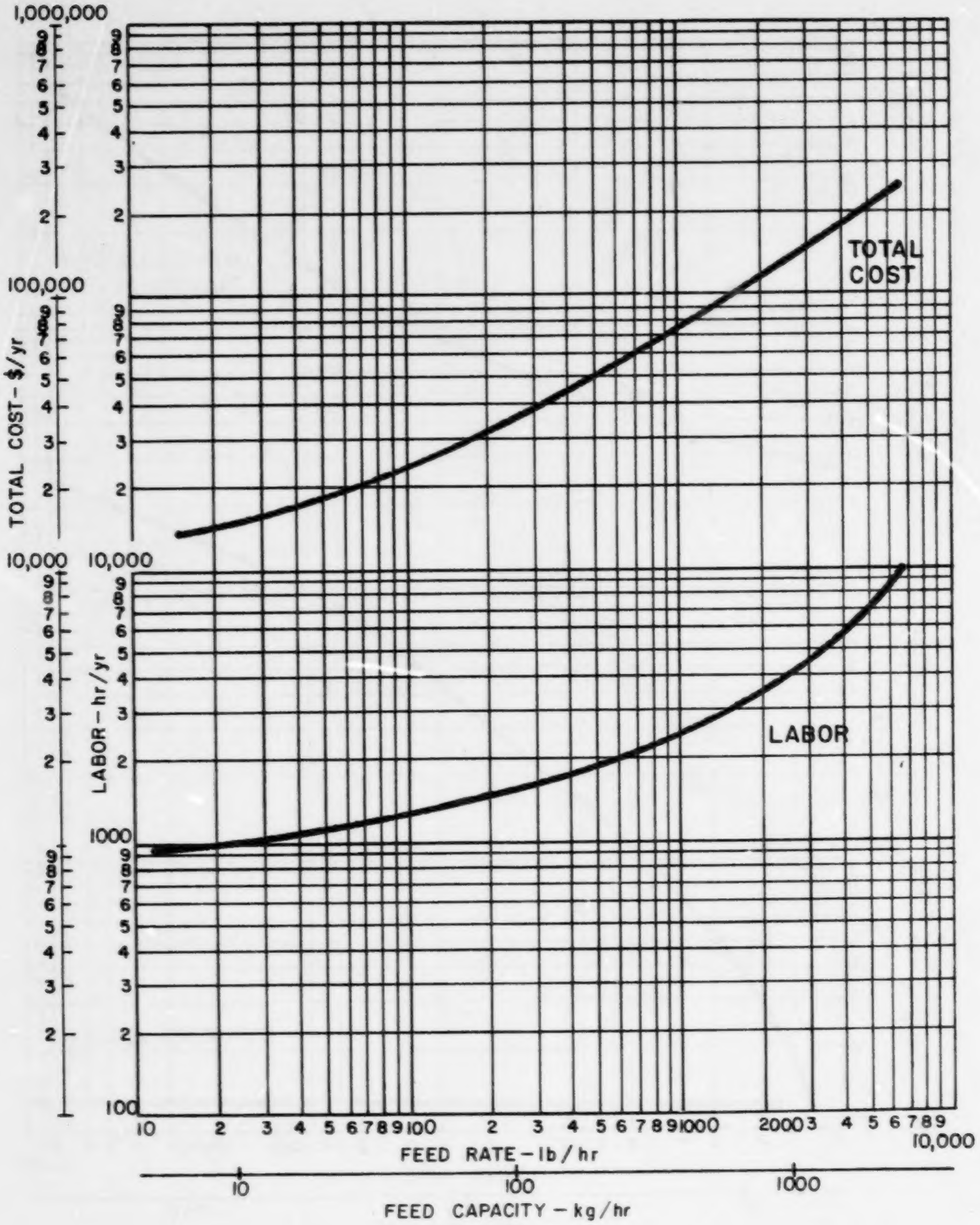


Figure 49. Operation and maintenance requirements for powdered activated carbon feed systems - labor and total cost.

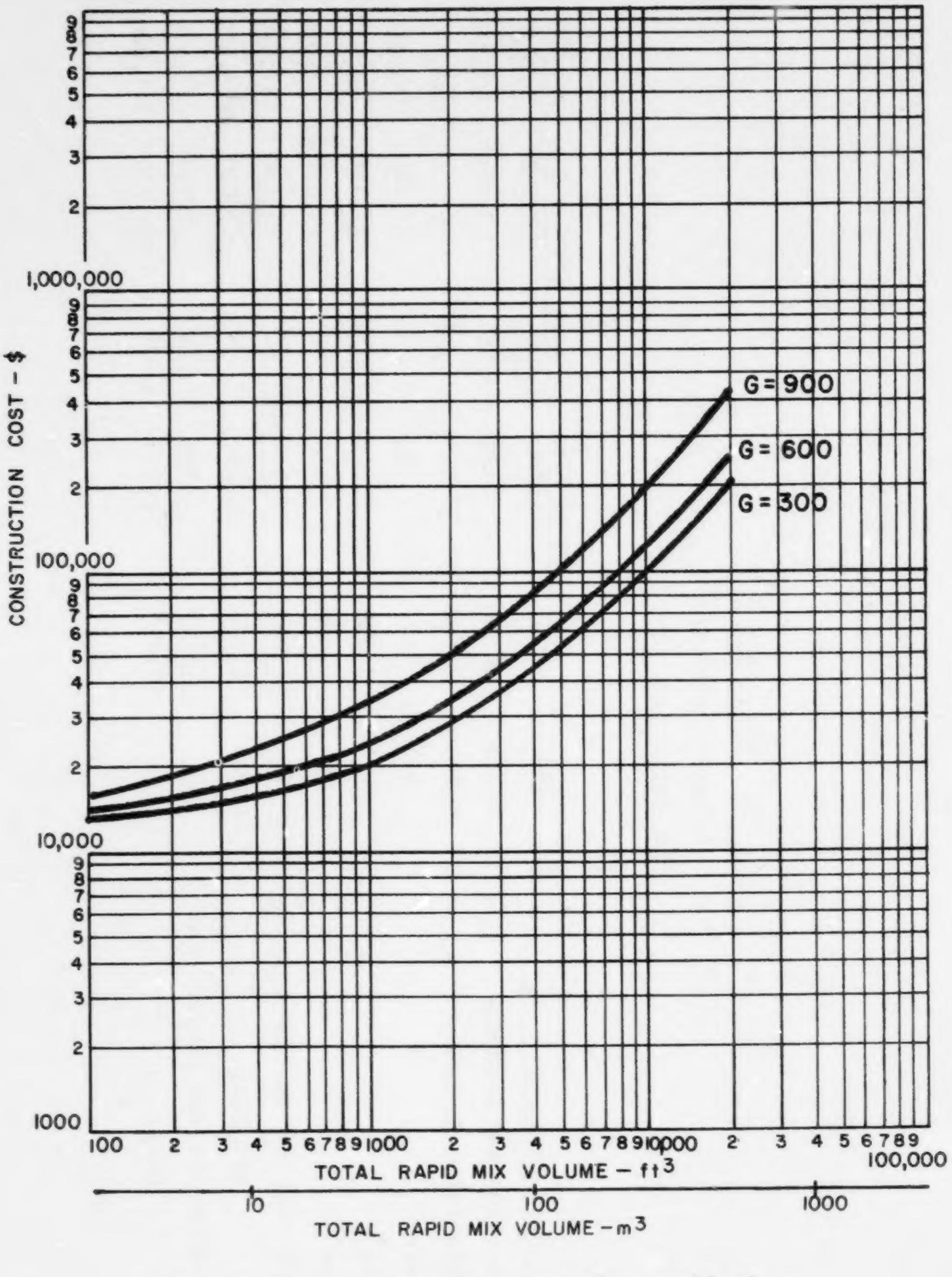


Figure 50. Construction cost for rapid mix.

Table 35

Construction Cost

for Rapid Mix, G = 300

Cost Category	Total Basin Volume (ft^3) 100	500	1,000	5,000	10,000	20,000
Excavation and Sitework	$ 220	$ 380	$ 490	$ 1,360	$ 2,720	$ 5,460
Manufactured Equipment	3,070	3,680	4,920	17,380	34,750	69,510
Concrete	390	870	1,280	3,610	7,220	14,450
Steel	570	1,350	2,010	5,600	11,180	22,360
Labor	1,230	2,300	3,410	8,500	17,020	34,040
Electrical and Instrumentation	6,980	6,980	6,980	10,760	20,130	37,680
SUBTOTAL	12,460	15,560	19,090	47,210	93,020	183,500
Miscellaneous and Contingency	1,870	2,330	2,860	7,080	13,950	27,520
TOTAL	14,330	17,890	21,950	54,290	106,970	211,020

Table 36

Construction Cost for Rapid Mix, G = 600

	Total Basin Volume (ft^3)					
Cost Category	100	500	1,000	5,000	10,000	20,000
Excavation and Sitework	$ 220	$ 380	$ 490	$1,360	$2,720	$5,460
Manufactured Equipment	3,450	4,920	7,380	26,730	53,470	106,940
Concrete	390	870	1,280	3,610	7,220	14,450
Steel	570	1,350	2,010	5,600	11,180	22,360
Labor	1,300	2,560	3,870	9,390	18,770	37,540
Electrical and Instrumentation	6,980	6,980	6,980	11,580	20,860	39,530
SUBTOTAL	12,910	17,060	22,010	58,270	114,220	226,280
Miscellaneous and Contingency	1,940	2,560	3,300	8,740	17,130	33,940
TOTAL	14,850	19,620	25,310	67,010	131,350	260,220

Table 37

Construction Cost

for Rapid Mix, G = 900

Cost Category	Total Basin Volume (ft^3)					
	100	500	1,000	5,000	10,000	20,000
Excavation and Sitework	$ 220	$ 380	$ 490	$ 1,360	$ 2,720	$ 5,460
Manufactured Equipment	4,310	9,830	14,760	66,840	133,670	267,340
Concrete	390	870	1,280	3,610	7,220	14,450
Steel	570	1,350	2,010	5,600	11,180	22,360
Labor	1,230	2,300	3,410	13,140	26,280	52,550
Electrical and Instrumentation	6,980	6,980	7,180	7,470	8,760	16,100
SUBTOTAL	13,700	21,710	29,130	98,020	189,830	378,260
Miscellaneous and Contingency	2,050	3,260	4,370	14,700	28,470	56,740
TOTAL	15,750	24,970	33,500	112,720	218,300	435,000

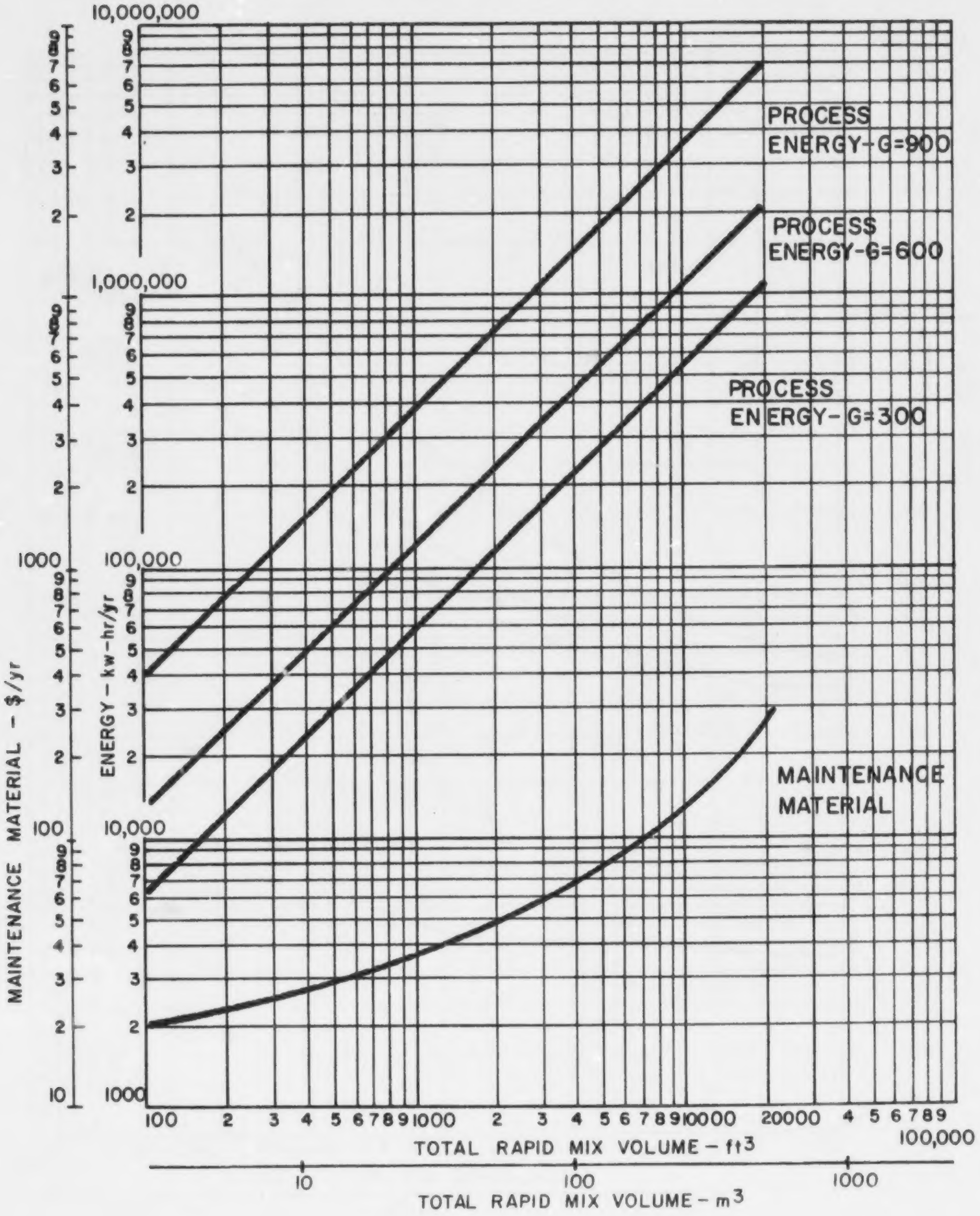


Figure 51. Operation and maintenance requirements for rapid mix - process energy and maintenance material.

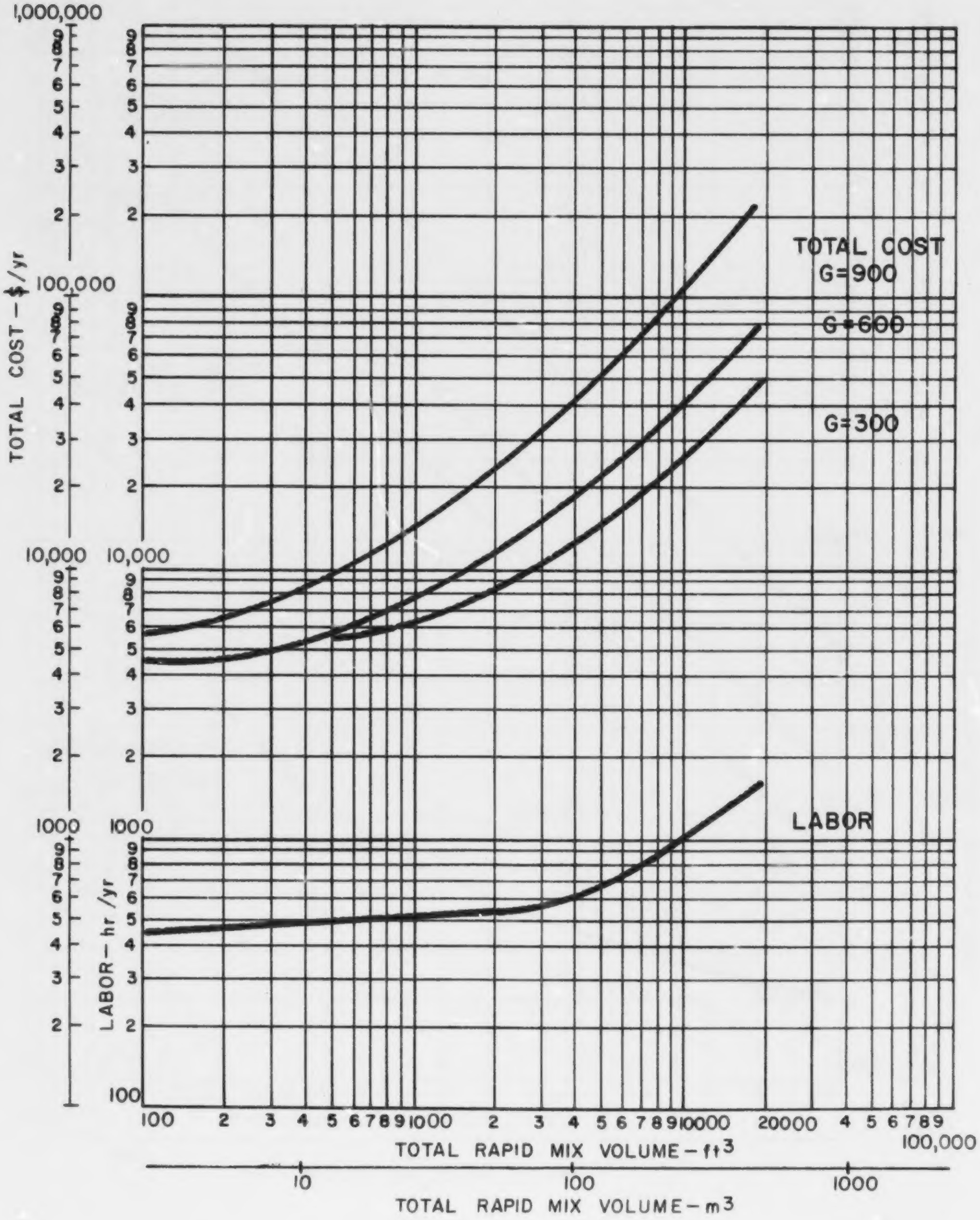


Figure 52. Operation and maintenance requirements for rapid mix - labor and total cost.

Table 38

Operation and Maintenance Summary for Rapid Mix

Total Basin Volume (ft^3)	Process Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost ($/yr)*		
	G = 300	G = 600	G = 900			G = 300	G = 600	G = 900
100	5,090	10,180	33,930	$ 20	470	$ 4,870	$ 5,030	$ 5,740
500	25,450	50,900	169,670	30	470	5,490	6,260	9,820
1,000	50,900	101,800	339,330	40	470	6,270	7,790	14,920
2,500	127,250	254,500	848,330	60	510	8,980	12,800	30,610
5,000	254,500	509,000	1,696,700	80	580	13,510	21,150	56,780
10,000	509,000	1,018,000	3,393,300	160	1,160	27,030	42,300	113,560
20,000	1,018,000	2,036,000	6,786,670	320	1,590	46,760	77,300	219,820

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

FLOCCULATION

Construction Cost

Estimated flocculation basin costs are for rectangular-shaped, reinforced concrete structures 12 ft deep. A length-to-width ratio of approximately 4:1 was used for basin sizing, and the maximum individual basin size utilized was 12,500 ft^3. Common wall construction was used where the total basin volume exceeded 12,500 ft^3. Structural costs for vertical turbine flocculators are somewhat higher that for the horizontal paddle type because of the required structural support above the basin. Costs were calculated for use of horizontal paddle flocculators and total basin volume of 1,800 to 1 million ft^3 (only 1,800 to 25,00 ft^3 for vertical turbine type). Horizontal paddles are less expensive for use in larger basins, and they generally provide more satisfactory operation in the larger basins, particularly when tapered flocculation is practiced.

G values of 20, 50, and 80 were used to calculate manufactured equipment costs. All drive units are variable speed to allow maximum flexibility. Although common drive for two or more parallel basins is commonly utilized, the estimated costs were calculated using individual drive for each basin. Estimated costs are shown in Figure 53 and Tables 39 to 41 for horizontal paddle systems and in Figure 54 and Table 42 for vertical turbine flocculators.

Operation and Maintenance Cost

Energy requirements for G values of 20, 50, and 80 were calculated on the basis of respective horsepower per unit volume requirements of 0.01, 0.06, and 0.17 foot-pounds/second per ft^3. An overall motor/mechanism efficiency of 60 percent was utilized.

Maintenance material costs are based on 3 percent of the manufactured equipment costs. Although equipment costs vary somewhat with the maximum design value for G, the maintenance material costs are based on a G value of 80.

Labor requirements are based on routine operation and maintenance of 15 min/day per basin (maximum basin volume = 12,500 ft^3) and an oil change every 6 months requiring 4 hr per change. No allowance is included for jar test time, as this is included in the rapid mix operation and maintenance curves.

Figures 55 and 56 present operation and maintenance requirements for G = 20, 50, and 80 for horizontal paddle flocculation. Costs for vertical turbine flocculators are nearly identical and are not shown separately. However, the cost curves are applicable to vertical turbine flocculators only up to basin volumes of 25,000 ft^3. Table 43 summarizes the operation and maintenance requirements.

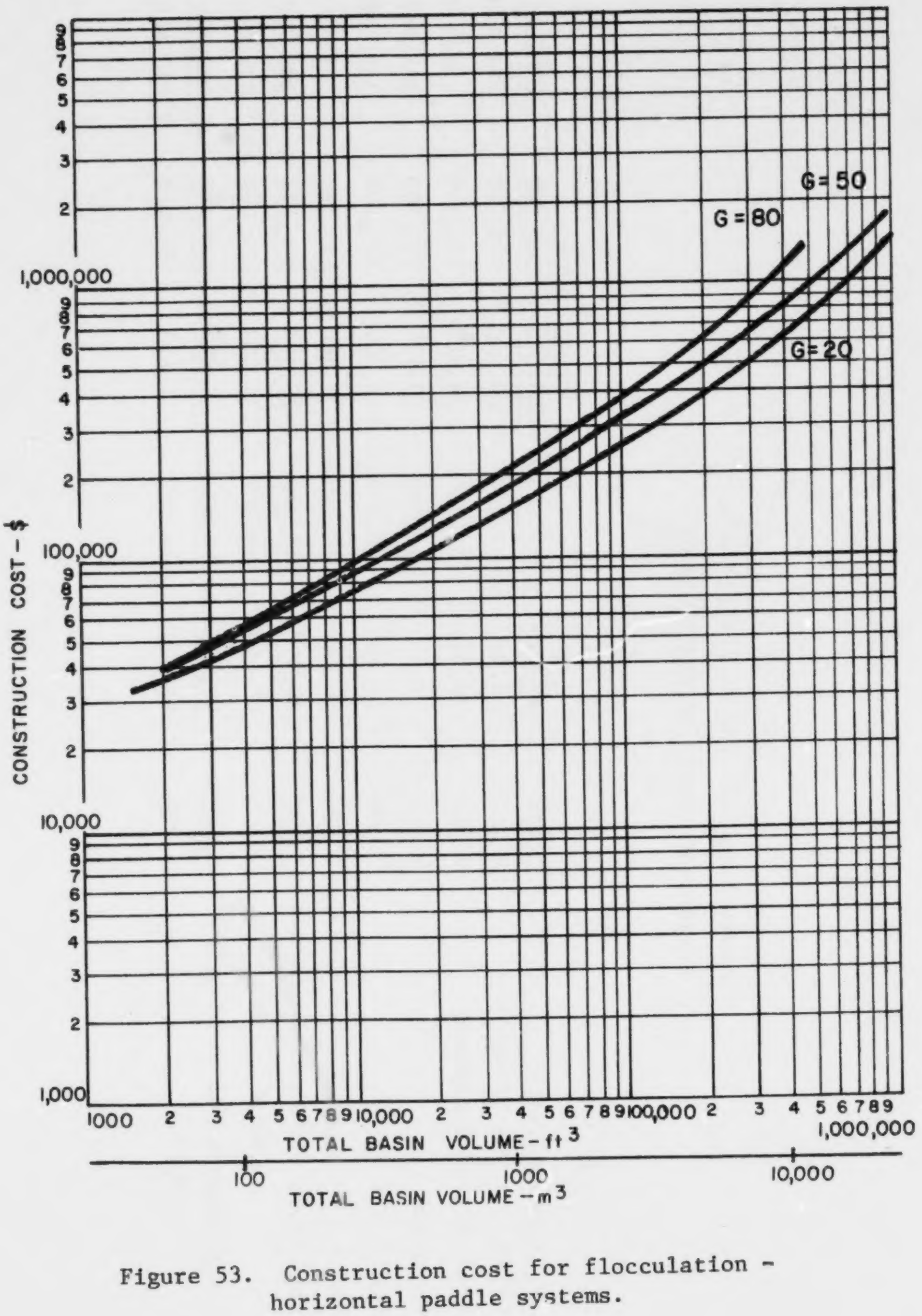


Figure 53. Construction cost for flocculation - horizontal paddle systems.

Table 39
Construction Cost for Flocculation - Horizontal Paddle Systems, G = 20

Cost Category	Total Basin Volume (ft^3)					
	1,800	10,000	25,000	100,000	500,000	1,000,000
Excavation and Sitework	$ 470	$ 2,550	$ 4,290	$ 9,970	$ 40,080	$ 77,640
Manufactured Equipment	12,140	28,240	31,420	54,500	118,350	232,730
Concrete	1,400	7,610	12,740	29,770	120,280	232,960
Steel	2,360	12,550	20,440	46,500	175,290	339,510
Labor	7,080	20,220	28,110	69,940	187,360	373,420
Electrical and Instrumentation	6,980	28,320	28,320	28,320	141,610	283,220
SUBTOTAL	30,430	99,490	125,320	239,000	782,970	1,539,480
Miscellaneous and Contingency	4,560	14,920	18,800	35,850	117,450	230,920
TOTAL	34,990	114,410	144,120	274,850	900,420	1,770,400

Table 40

Construction Cost for Flocculation - Horizontal Paddle Systems, G = 50

Cost Category	Total Basin Volume (ft^3)					
	1,800	10,000	25,000	100,000	500,000	1,000,000
Excavation and Sitework	$ 470	$2,550	$4,290	$ 9,970	$40,080	$ 77,640
Manufactured Equipment	12,140	28,250	35,410	74,400	220,800	433,640
Concrete	1,400	7,610	12,740	29,770	120,280	232,960
Steel	2,360	12,550	20,440	46,500	175,290	339,510
Labor	7,080	20,220	29,420	75,460	221,200	439,770
Electrical and Instrumentation	6,980	28,320	28,320	28,320	141,610	283,220
SUBTOTAL	30,430	99,500	130,620	264,420	919,260	1,806,740
Miscellaneous and Contingency	4,560	14,920	19,590	39,660	137,890	271,010
TOTAL	34,990	114,420	150,210	304,080	1,057,150	2,077,750

Table 41

Construction Cost for Flocculation - Horizontal Paddle Systems, G = 80

Cost Category	Total Basin Volume (ft^3)				
	1,800	10,000	25,000	100,000	500,000
Excavation and Sitework	$ 470	$ 2,550	$ 4,290	$ 9,970	$ 40,080
Manufactured Equipment	12,140	34,210	44,360	115,770	427,670
Concrete	1,400	7,610	12,740	29,770	120,280
Steel	2,360	12,550	20,440	46,500	175,290
Labor	7,080	22,190	32,370	90,170	289,520
Electrical and Instrumentation	6,980	28,320	28,320	28,320	141,610
SUBTOTAL	30,430	107,430	142,520	320,500	1,194,450
Miscellaneous and Contingency	4,560	16,110	21,380	48,070	179,170
TOTAL	34,990	123,540	163,900	368,570	1,373,620

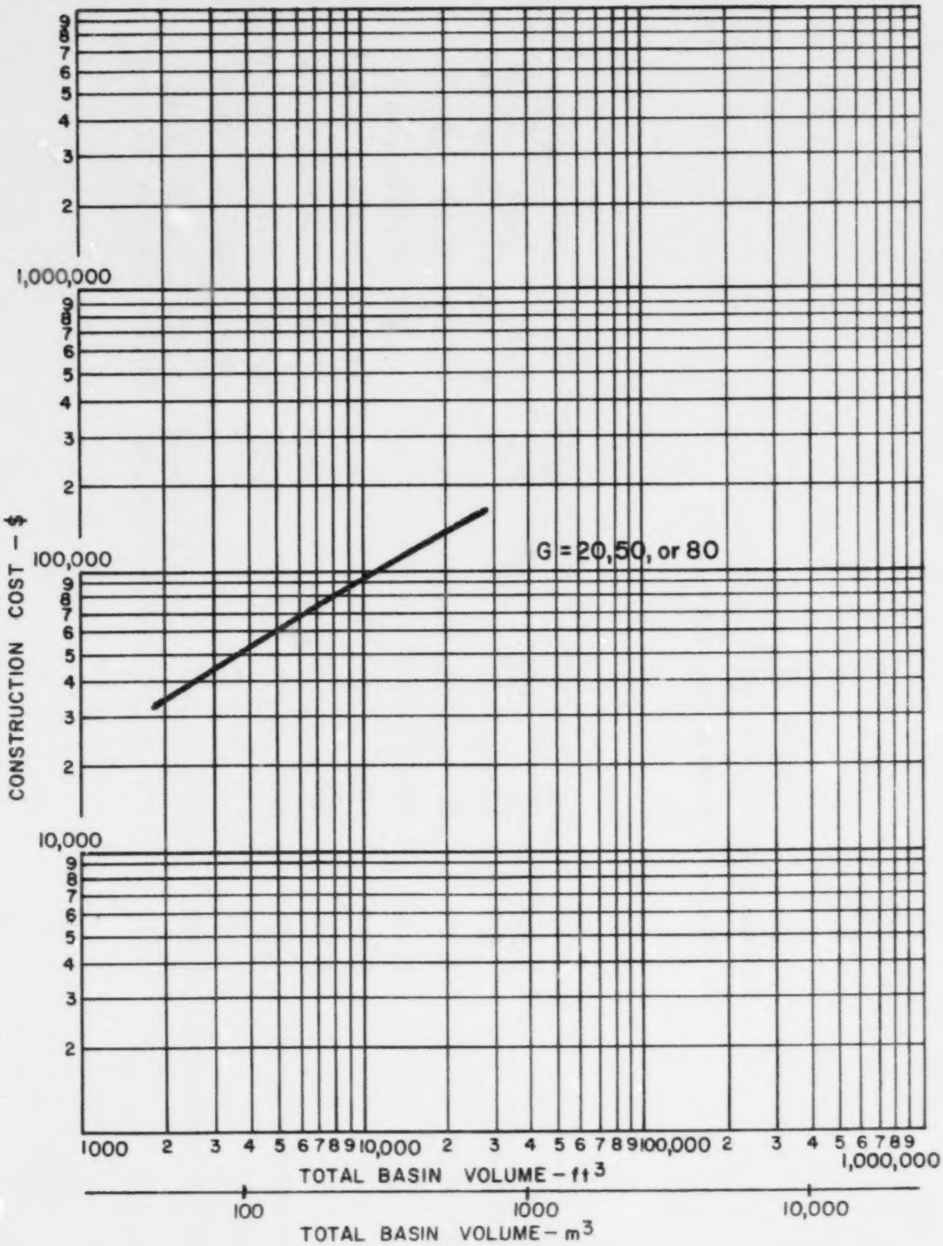


Figure 54. Construction cost for flocculation - vertical turbine flocculators.

Table 42

Construction Cost for Flocculation - Vertical Turbine Flocculators

Cost Category	Total Basin Volume (ft^3) 1,800 G=20	1,800 G=50	1,800 G=80	10,000 G=20	10,000 G=50	10,000 G=80	25,000 G=20	25,000 G=50	25,000 G=80
Excavation and Sitework	$ 630	$ 630	$ 630	$ 2,520	$ 2,520	$ 2,520	$ 3,250	$ 3,250	$ 3,250
Manufactured Equipment	7,300	7,300	7,300	14,640	15,910	15,910	29,170	29,170	34,480
Concrete	1,930	1,930	1,930	7,720	7,720	7,720	12,300	12,300	12,300
Steel	3,170	3,170	3,170	12,470	12,470	12,470	19,400	19,400	19,400
Labor	7,240	7,240	7,240	22,100	22,470	22,470	37,070	37,070	38,380
Electrical and Instrumentation	6,980	6,930	6,980	28,320	28,320	28,320	28,320	28,320	28,320
SUBTOTAL	27,250	27,250	27,250	87,770	89,410	89,410	129,510	129,510	136,130
Miscellaneous and Contingency	4,090	4,090	4,090	13,170	13,410	13,410	19,430	19,430	20,420
TOTAL	31,340	31,340	31,340	100,940	102,820	102,820	148,940	148,940	156,550

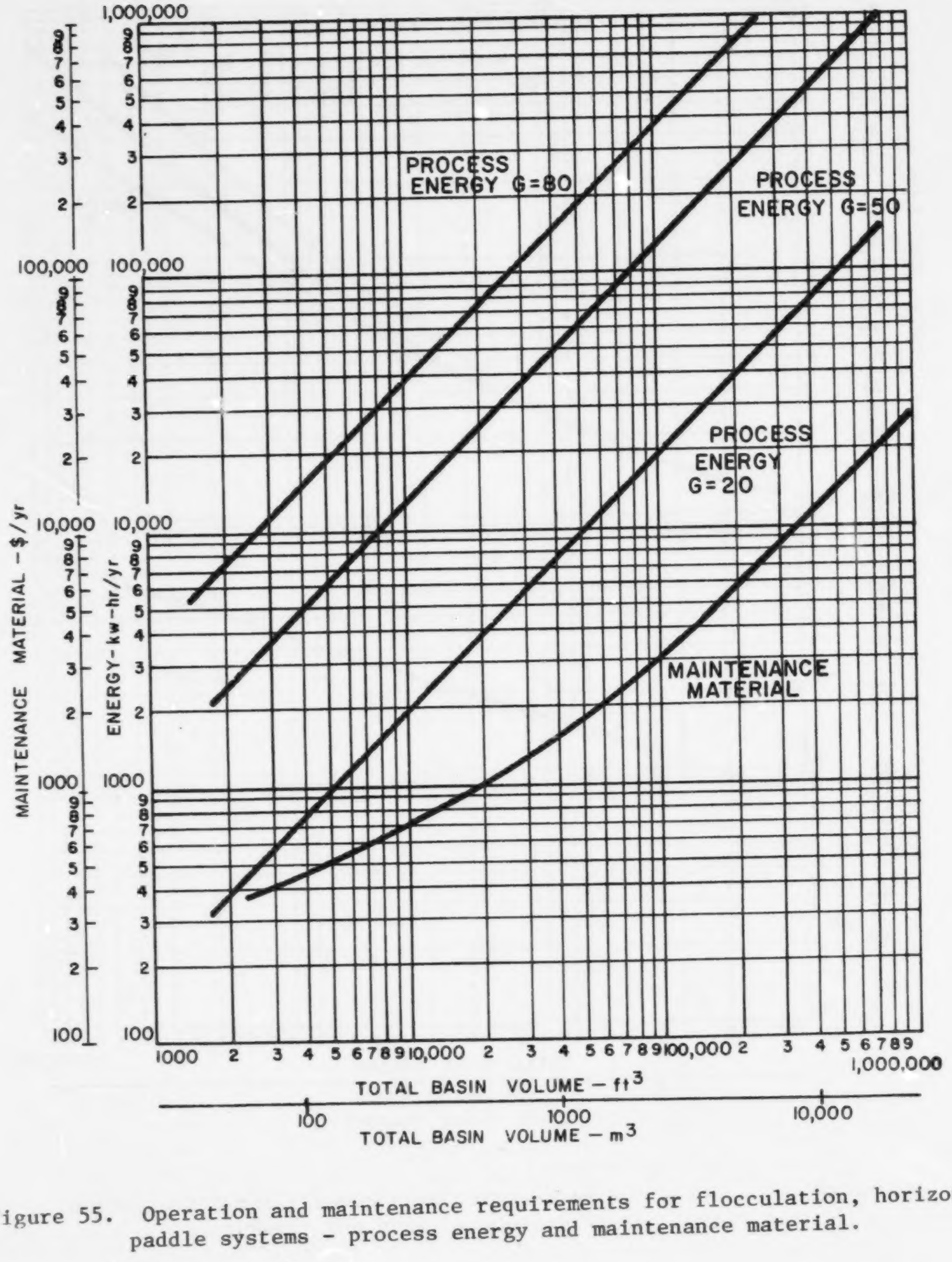


Figure 55. Operation and maintenance requirements for flocculation, horizontal paddle systems - process energy and maintenance material.

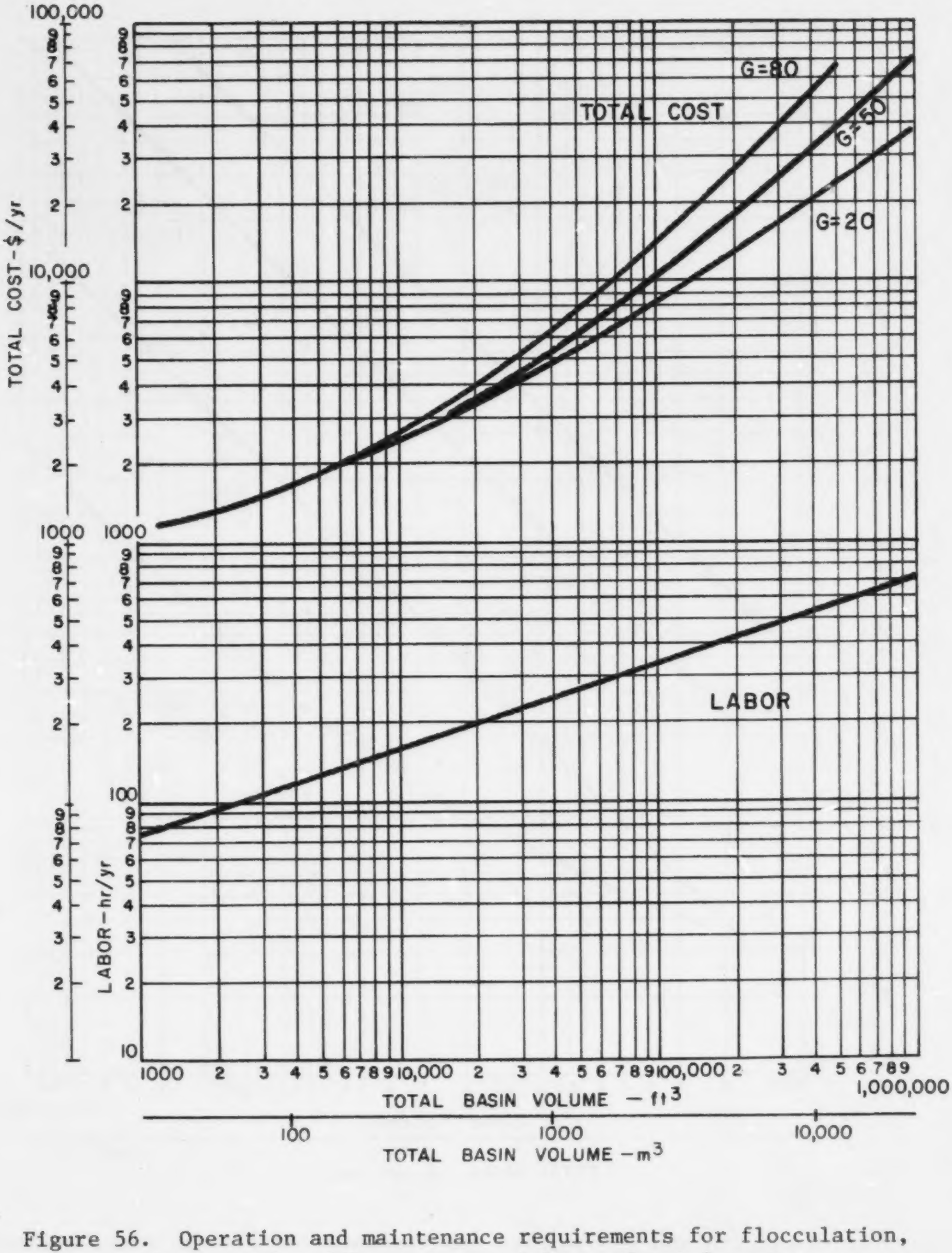


Figure 56. Operation and maintenance requirements for flocculation, horizontal paddle systems - labor and total cost.

Table 43

Operation and Maintenance Summary

Flocculation - Horizontal Paddle Systems

Total Basin Volume (ft^3)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost ($/yr)*		
	G = 20	G = 50	G = 80			G = 20	G = 50	G = 80
1,800	330	2,070	6,100	$ 410	99	$ 1,410	$1,460	$1,580
10,000	1,960	11,870	33,660	1,050	199	3,100	3,400	4,050
25,000	4,900	29,630	84,080	1,050	199	3,190	3,930	5,560
100,000	19,600	118,720	336,550	4,010	397	8,570	11,540	18,080
500,000	98,020	593,590	1,682,750	14,430	496	22,330	37,200	69,870
1,000,000	198,230	1,188,300	--	28,860	990	44,710	74,410	--

*Calculated using $0.03/kw-hr and $10.00/hr of labor

CIRCULAR CLARIFIERS

Construction Cost

Circular clarifiers may be used for the removal of settleable solids in water, either before treatment or following treatment by softening or coagulation and flocculation. Cost estimates were made for center feed circular clarifiers with a 12-ft sidewall depth, and for sludge removal from a sump located at the circular center.

The construction cost estimates include the center feed clarifier mechanism, weirs, baffles, troughs, and a circular reinforced concrete structure. For clarifier diameters greater than 80 ft, an inboard steel weir trough was also included. Piping to and from the clarifier is not included in the cost estimates.

Table 44 presents the construction costs for circular clarifiers with diameters between 30 and 200 ft; the costs are also shown in Figure 57.

Operation and Maintenance Cost

Process energy requirements were calculated using manufacturers' estimates of motor size and torque requirements for alum, ferric, and lime sludges. The heavier lime sludge calls for an approximate 50-percent increase in power requirements.

Maintenance material costs are for parts required for periodic maintenance of the drive mechanism and weirs. Labor requirements are for periodic checking of the clarifier drive mechanism, as well as periodic maintenance of the mechanism and weirs.

Operation and maintenance requirements are summarized in Table 45 and are also shown in Figures 58 and 59.

RECTANGULAR CLARIFIERS

Construction Cost

Rectangular clarifiers may be used following treatment by coagulation and flocculation or by softening. Cost estimates were made for clarifiers that have a 12-ft sidewall depth and that use chain and flight sludge collectors.

The construction cost includes the chain and flight collector, the collector drive mechanism, weirs, the reinforced concrete structure complete with inlet and outlet troughs, a sludge sump, and sludge withdrawal piping. Costs for the structure were developed assuming multiple units with common wall construction. Yard piping to and from the clarifier is not included in the cost estimates.

Construction cost estimates for rectangular clarifiers are presented in Table 46 and in Figure 60.

Table 44

Construction Cost for

Circular Clarifiers

	Surface Area (SA = ft^2) and Diameter (ft)						
Cost Category	707 SA 30 ft	1,590 SA 45 ft	5,027 SA 80 ft	10,387 SA 115 ft	15,393 SA 140 ft	22,698 SA 170 ft	31,416 SA 200 ft
Excavation & Sitework	$ 1,530	$ 2,430	$ 4,900	$ 7,860	$ 10,280	$ 13,520	$ 17,130
Manufactured Equipment	28,740	34,410	69,580	97,180	132,350	189,060	226,980
Concrete	4,860	7,710	15,480	24,800	32,400	42,560	53,860
Steel	14,160	21,090	67,240	129,250	188,720	249,570	335,140
Labor	10,770	16,180	30,960	46,980	60,110	77,640	96,320
Pipe and Valves	8,090	8,420	11,540	15,660	21,590	26,590	42,520
Electrical & Instrumentation	5,940	5,940	7,560	8,270	10,870	12,370	13,060
SUBTOTAL	74,090	96,180	207,260	330,000	456,320	611,310	785,010
Miscellaneous & Contingency	11,110	14,430	31,090	49,500	68,450	91,700	117,760
TOTAL	85,200	110,610	238,350	379,500	524,770	703,010	902,760

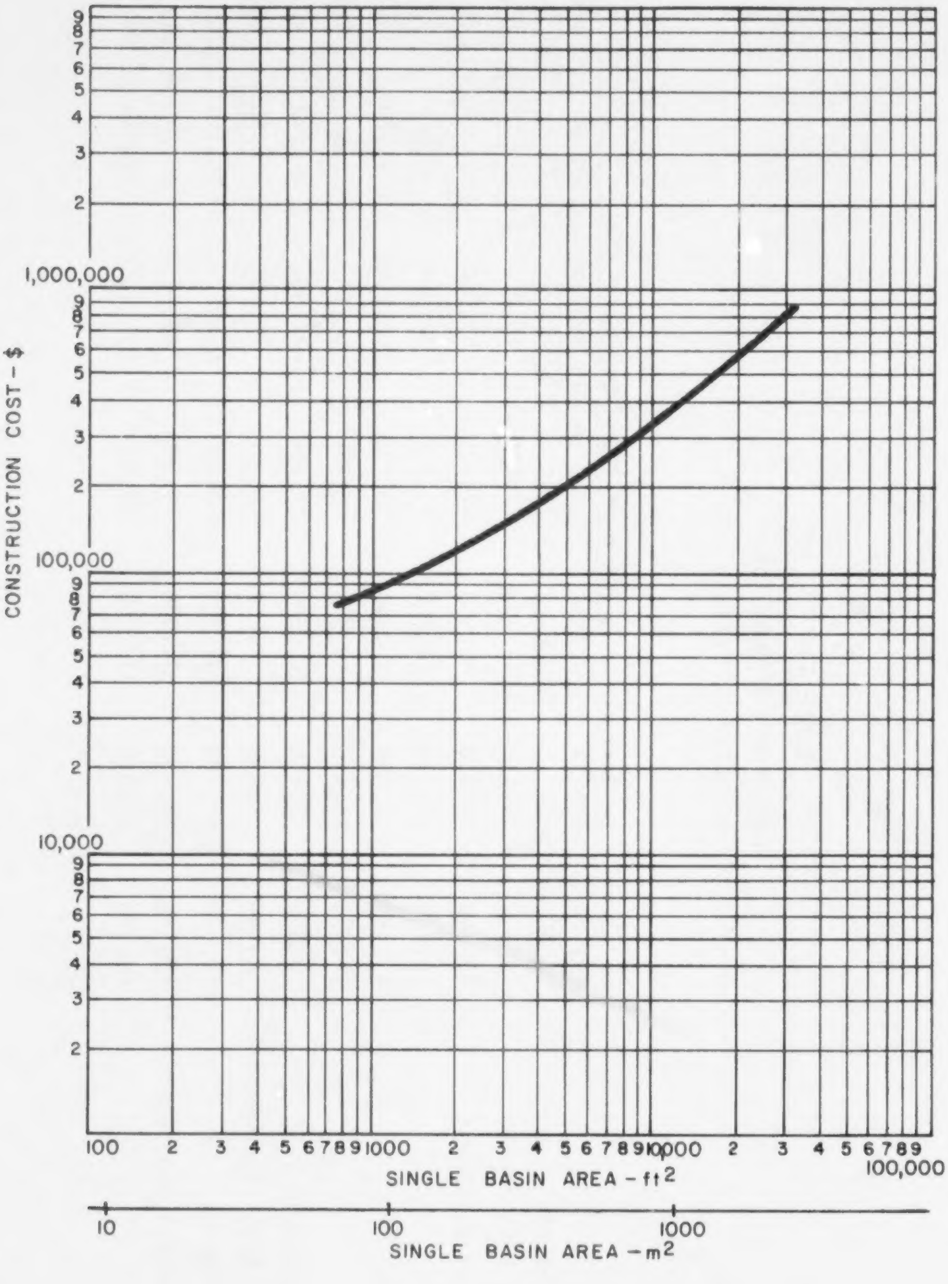


Figure 57. Construction cost for circular clarifiers.

Table 45

Operation and Maintenance Summary for Circular Clarifiers

Clarifier Size		Energy (kw-hr/yr)		Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost ($/yr)*	
Diameter ft	Area ft	Lime Sludge	Ferric & Alum Sludge			Lime Sludge	Ferric & Alum Sludge
30	707	4,900	3,270	$ 250	150	$ 1,900	$ 1,850
45	1,590	5,380	3,760	420	170	2,280	2,230
80	5,027	6,540	4,900	1,050	230	3,550	3,500
115	10,387	8,820	6,050	1,750	310	5,110	5,030
140	15,394	10,450	7,190	2,300	360	6,210	6,120
170	22,698	12,420	9,150	3,050	420	7,620	7,520
200	31,416	14,380	11,100	4,100	500	9,530	9,430

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

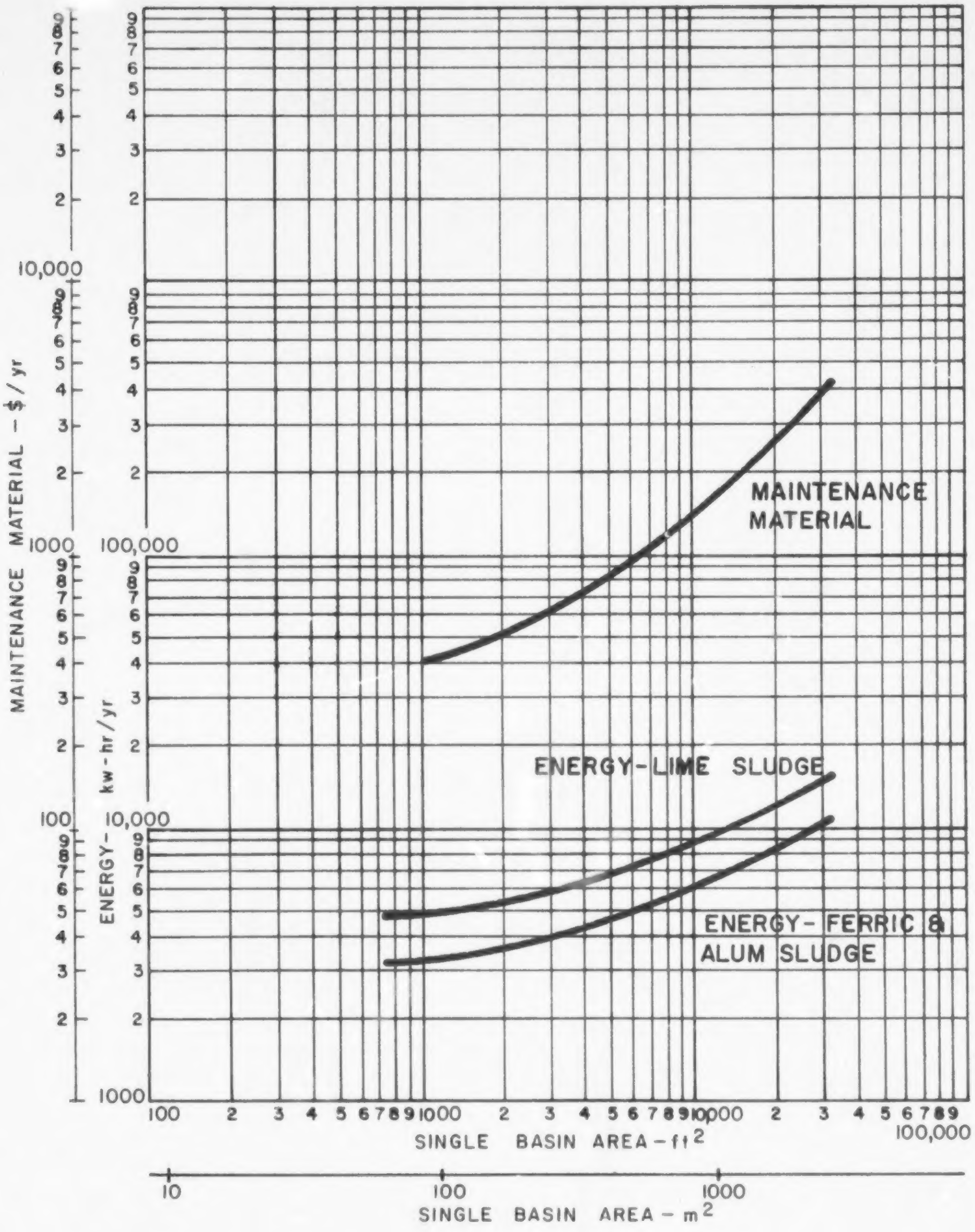


Figure 58. Operation and maintenance requirements for circular clarifiers - process energy and maintenance material.

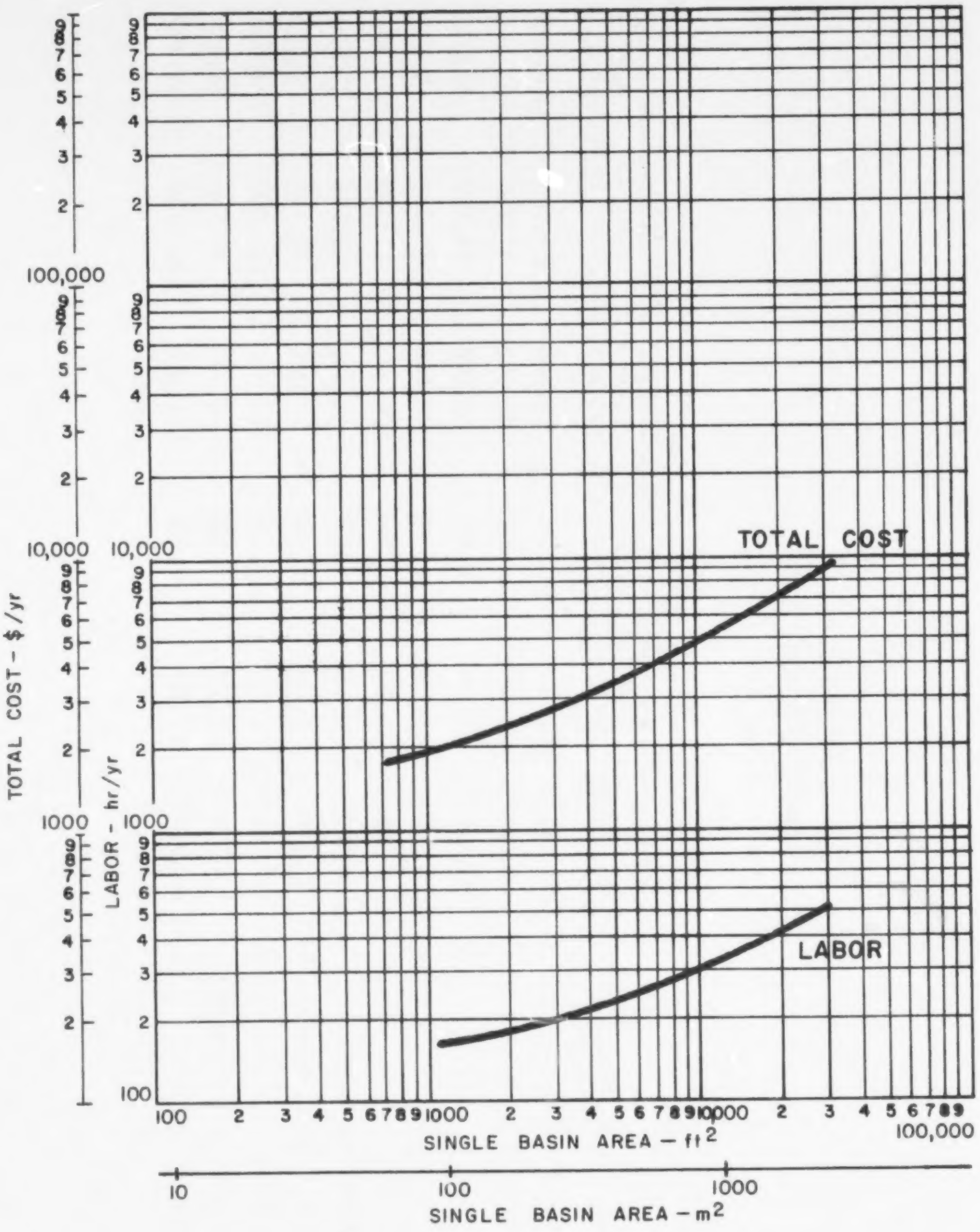


Figure 59. Operation and maintenance requirements for circular clarifiers - labor and total cost.

Table 46

Construction Cost for Rectangular Clarifiers

Cost Category	Area (ft^2) and Length x Width (ft)					
	240 ft^2 30 x 8 ft	600 ft^2 60 x 10 ft	1,260 ft^2 90 x 14 ft	2,240 ft^2 140 x 16 ft	3,600 ft^2 200 x 18 ft	4,800 ft^2 240 x 20 ft
Excavation & Sitework	$ 1,060	$ 2,000	$ 3,060	$ 4,680	$ 6,670	$ 8,090
Manufactured Equipment	8,540	12,080	24,470	32,020	53,110	63,440
Concrete	2,970	5,490	8,430	12,820	18,190	22,070
Steel	6,400	13,110	19,440	32,620	51,250	69,680
Labor	6,220	11,260	17,320	26,390	37,570	45,300
Pipe and Valves	6,960	7,400	9,100	12,500	16,100	21,450
Electrical & Instrumentation	1,510	1,760	1,860	2,020	2,110	2,400
SUBTOTAL	33,660	53,100	83,680	123,050	185,000	232,430
Miscellaneous & Contingency	5,050	7,670	12,550	18,460	27,750	34,860
TOTAL	38,710	61,070	96,230	141,510	212,750	267,290

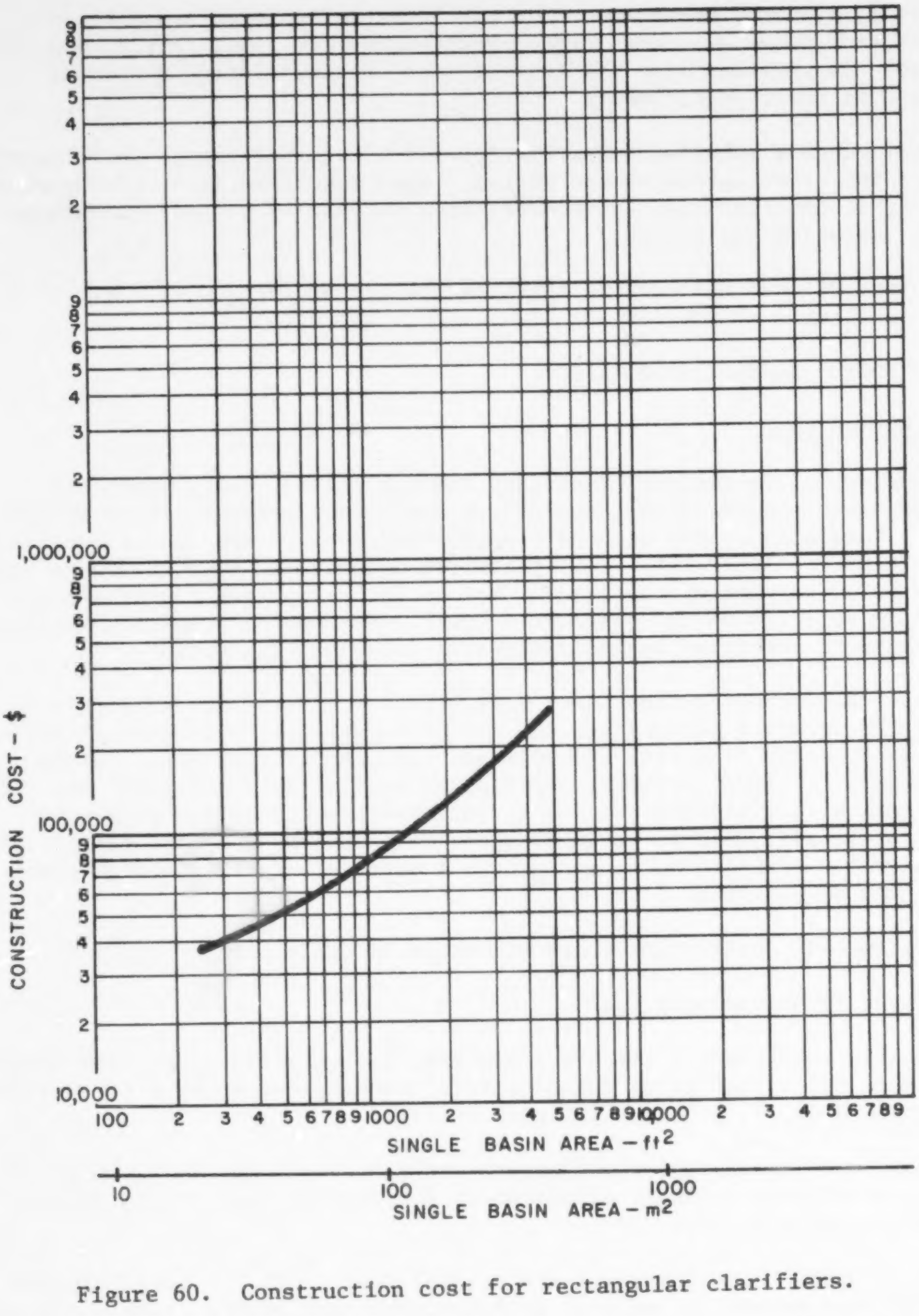


Figure 60. Construction cost for rectangular clarifiers.

Operation and Maintenance Cost

Process energy requirements were calculated based on manufacturers' estimates of motor size and torque requirements for alum, ferric, and lime sludges. The heavier lime sludges call for an approximate 50-percent increase in power requirements.

Maintenance material costs are for parts required for periodic maintenance of the drive mechanism and weirs. Labor requirements are for periodic checking of the clarifier drive mechanism, as well as periodic maintenance of the mechanism and weirs.

Operation and maintenance requirements are summarized in Table 47 and shown in Figures 61 and 62.

UPFLOW SOLIDS CONTACT CLARIFIERS

Construction Cost

Upflow solids contact clarifiers combine mixing, coagulation and flocculation, liquid-solids separation, and sludge removal into a single basin. Generally, rapid mix and coagulation/flocculation are accomplished in the center of the unit, with upflow clarification through a sludge blanket in the outer portion of the basin. Upflow solids contact clarifiers are generally selected on the bases of a lower cost and the operational advantages of combining several processes into a single basin.

Estimated construction costs were made for circular units within a reinforced concrete structure. The factory-manufactured reactor clarifier unit was a center feed type and included all mixers, the center column (when used), a sludge scraper, and a steel wall between the inner and outer compartments. Units less than 45 ft in diameter were bridge supported, and those greater than 45 ft in diameter were supported by the center column. All units were assumed to have a sidewall depth of 16 ft, although greater depths may be utilized.

Estimated construction costs are shown in Table 48 and Figure 63.

Operation and Maintenance Cost

Energy requirements for the flash mix, flocculation mixer, and mechanism drive were calculated using manufacturers' recommended motor sizes. Flash mix G values of 70, 110, and 150 were utilized.

Maintenance material requirements are relatively low for upflow solids contact clarifiers and were estimated at 1.5 percent/year of the initial clarifier mechanism cost.

Labor requirements are for operational control of the coagulant dose and the clarifier mechanism, as well as for maintenance of the drive units and mixers. A daily requirement of 1 hr/clarifier was used for jar testing to determine coagulant dose. Adjustment of the labor requirement for daily jar testing may be necessary if there is more than one clarifier.

Table 47

Operation and Maintenance Summary for Rectangular Clarifiers

Clarifier Size		Process Energy (kw-hr/yr)		Maintenance	Labor	Total Cost* ($/yr)	
Area (ft^2)	LxW (ft)	Lime Sludge	Alum Sludge	Material ($/yr)	(hr/yr)	Lime Sludge	Alum Sludge
240	30 x 8	3,270	3,270	$ 280	170	$ 2,080	$ 2,080
600	60 x 10	3,700	3,560	350	200	2,460	2,460
900	80 x 12	4,060	3,790	400	220	2,720	2,710
1,260	90 x 14	4,490	4,100	400	250	3,030	3,020
1,600	100 x 16	4,900	4,380	500	280	3,450	3,430
2,240	140 x 16	6,040	4,900	610	330	4,090	4,060
2,520	140 x 18	6,540	5,250	650	360	4,450	4,410
3,600	200 x 18	9,000	6,540	850	420	5,320	5,250
4,000	200 x 20	9,800	7,980	980	460	5,870	5,820
4,800	240 x 20	12,400	8,500	1,250	510	6,720	6,610

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

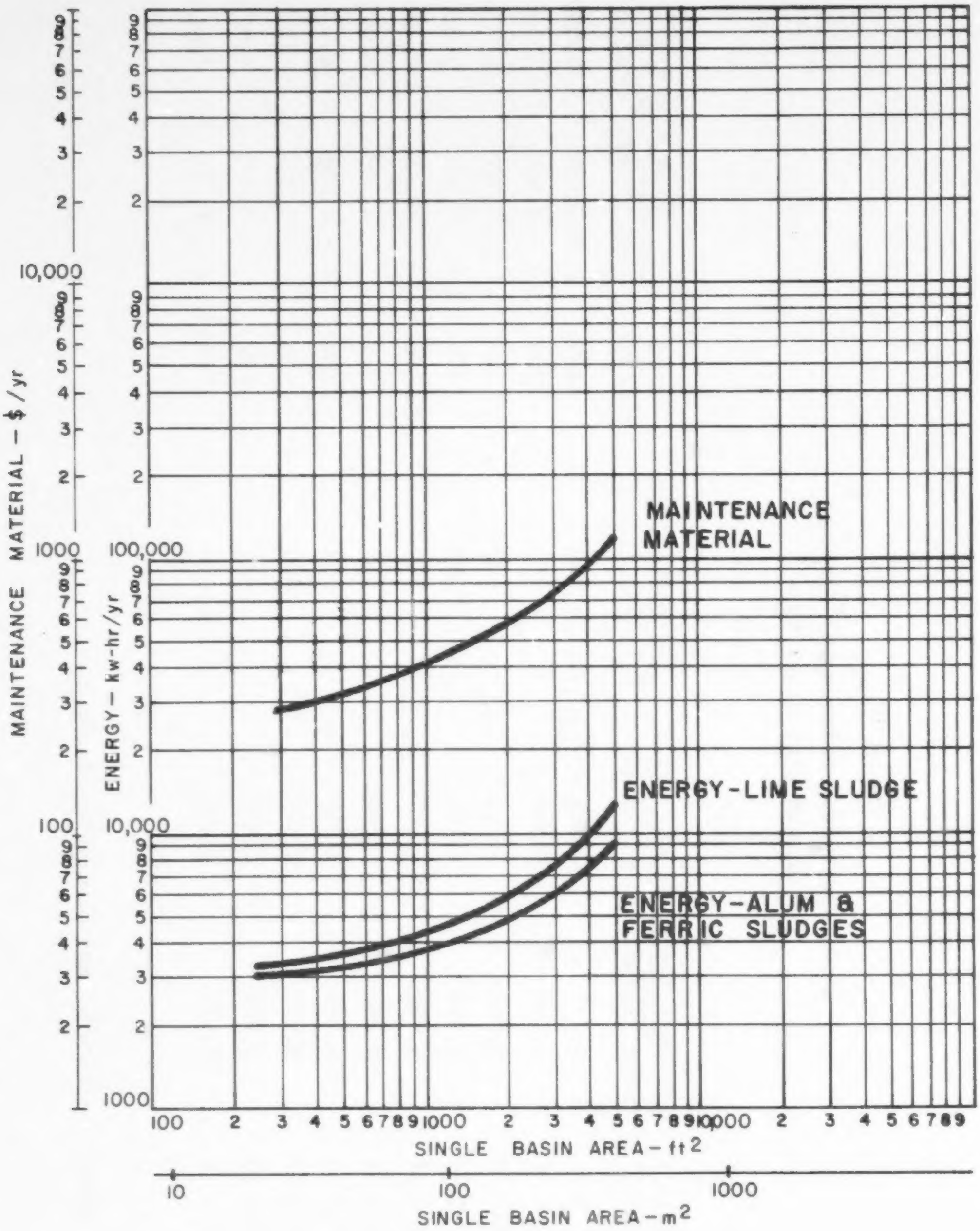


Figure 61. Operation and maintenance requirements for rectangular clarifiers - process energy and maintenance material.

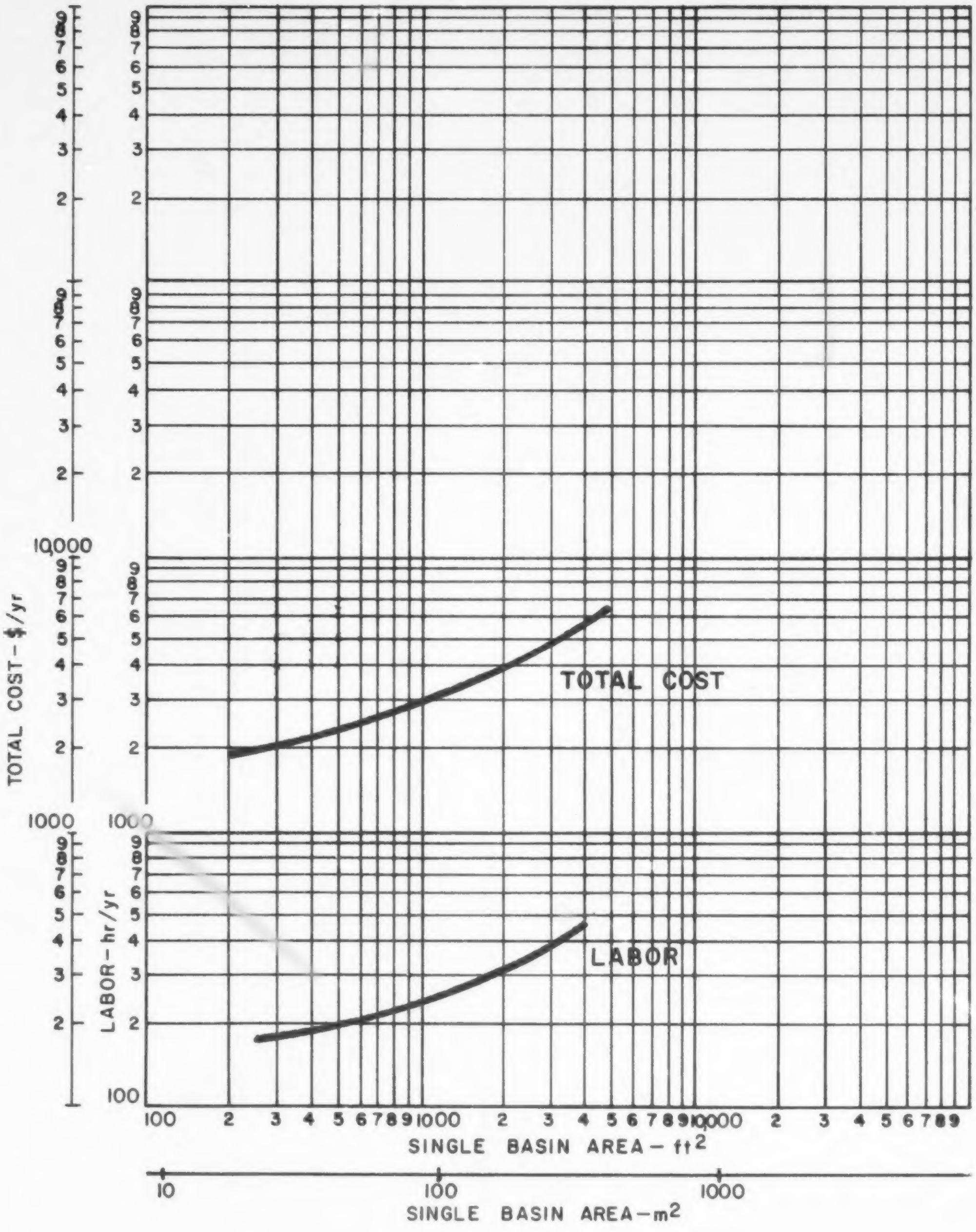


Figure 62. Operation and maintenance requirements for rectangular clarifiers - labor and total cost.

Table 48

Construction Cost for

Upflow Solids Contact Clarifiers

Cost Category	Net Effective Settling Area (ft^2) and Diameter (ft)						
	255 ft^2 20 ft	643 ft^2 30 ft	1,457 ft^2 45 ft	2,544 ft^2 60 ft	4,455 ft^2 80 ft	10,370 ft^2 125 ft	14,544 ft^2 150 ft
Excavation & Sitework	$ 1,460	$ 2,380	$ 4,000	$ 5,920	$ 8,920	$ 17,570	$ 23,510
Manufactured Equipment	41,500	47,000	65,000	86,000	122,500	186,250	230,000
Concrete	3,590	5,570	8,780	12,270	17,370	30,700	39,200
Steel	5,310	8,160	12,650	17,430	24,240	41,360	51,970
Labor	15,700	20,700	30,380	40,950	57,200	91,980	114,100
Electrical & Instrumentation	2,140	2,140	2,140	2,140	2,140	2,210	2,210
SUBTOTAL	69,700	85,950	122,950	164,710	232,370	370,070	460,990
Miscellaneous & Contingency	10,460	12,890	18,440	24,710	34,860	55,510	69,150
TOTAL	80,160	98,840	141,390	189,420	267,230	425,580	530,140

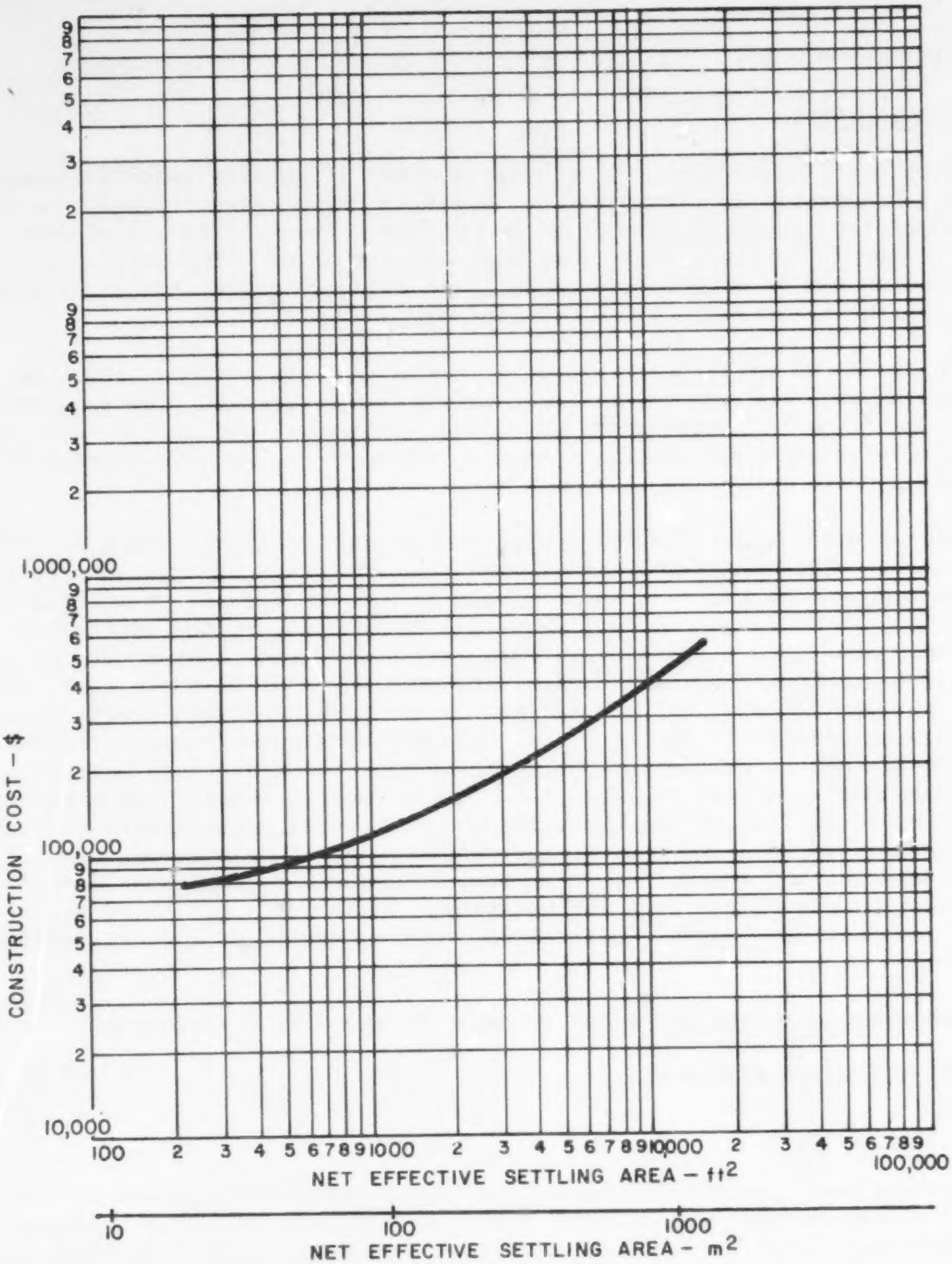


Figure 63. Construction cost for upflow solids contact clarifiers.

Figures 64 and 65 present the estimated operation and maintenance requirements for upflow solids contact clarifiers, and Table 49 summarizes these requirements.

TUBE SETTLING MODULES

Construction Cost

Tube settling modules employing principles of shallow depth sedimentation can be incorporated in clarification basins to reduce significantly the size and associated construction cost of new basins. The modules may also be used to improve performance or increase capacity at existing facilities. Tube modules may be applied successfully in circular or rectangular basins of either the horizontal flow or upflow design.

In basins of either rectangular or circular configuration, the tube modules that are constructed of light weight, high-strength plastic, are simply supported by light-weight structural members. Tube modules are available from numerous manufacturers in widths of 2.5 to 3.0 ft and in lengths up to 12 ft.

Conceptual designs that were used in the cost estimates are presented in Table 50. The basins were sized with rise rates through the area covered by tube modules and over the entire basin of 2.5 gpm/ft^2 amd 2 gpm/ft^2, respectively. By leaving a portion of the basin open, a zone is created for inlet turbulence dissipation. This transition zone is separated by a baffle extending from the bottom of the modules to 6 in. above the operating water level. Uniform effluent collection is a requirement for optimum utilization of tube settlers. To meet this requirement, effluent launders are spaced at 12-ft centers in all basins. Basin configurations and widths were selected to limit tube module support member length to a maximum of 20 ft. Since the hydraulic and structural requirements for tube clarification systems are unique, the costs include tube modules, tube module supports and anchor brackets, transition baffle, effluent launders with V-notch weir plates, and installation. These costs may be added to the cost of conventional basin construction costs to arrive at a total facility cost.

Construction costs are shown in Table 51 and also in Figure 66.

GRAVITY FILTRATION STRUCTURES

Construction Cost

Conventional gravity filtration structure costs are based on use of cast-in-place concrete with a media depth of 2 to 3 ft and a total depth of 16 ft for the filter box. Construction cost estimates have been based on the conceptual designs outlined in Table 52. At flows less than 5 mgd, two filters were used, but at 5 mgd and greater, a minimum of four filters was utilized. Maximum filter size was limited to 1,275 ft^2, and above 700 ft^2, the filters are dual-celled to allow backwashing of each half separately. This approach allows a significant reduction in the size of wash water and

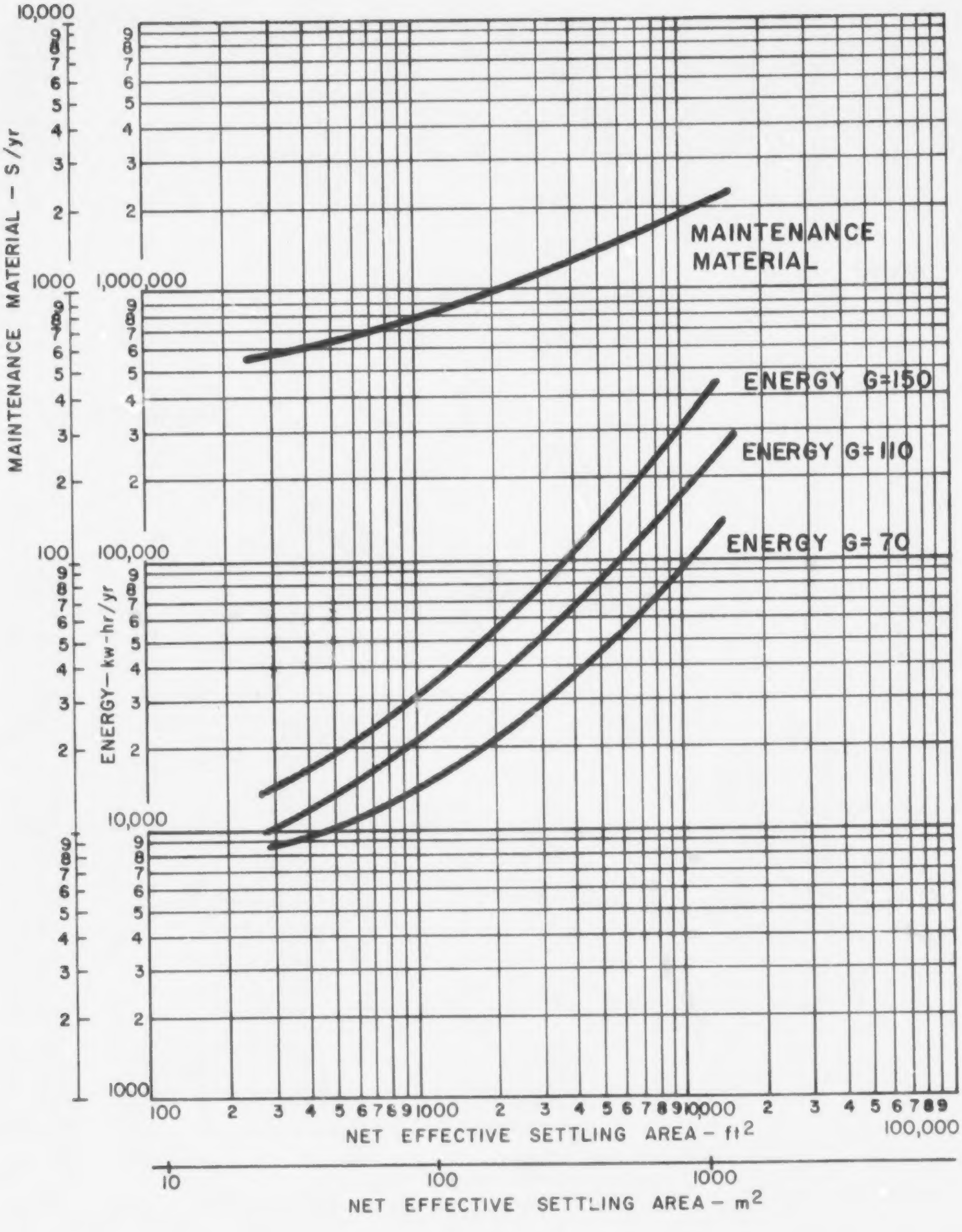


Figure 64. Operation and maintenance requirements for upflow solids contact clarifiers - process energy and maintenance material.

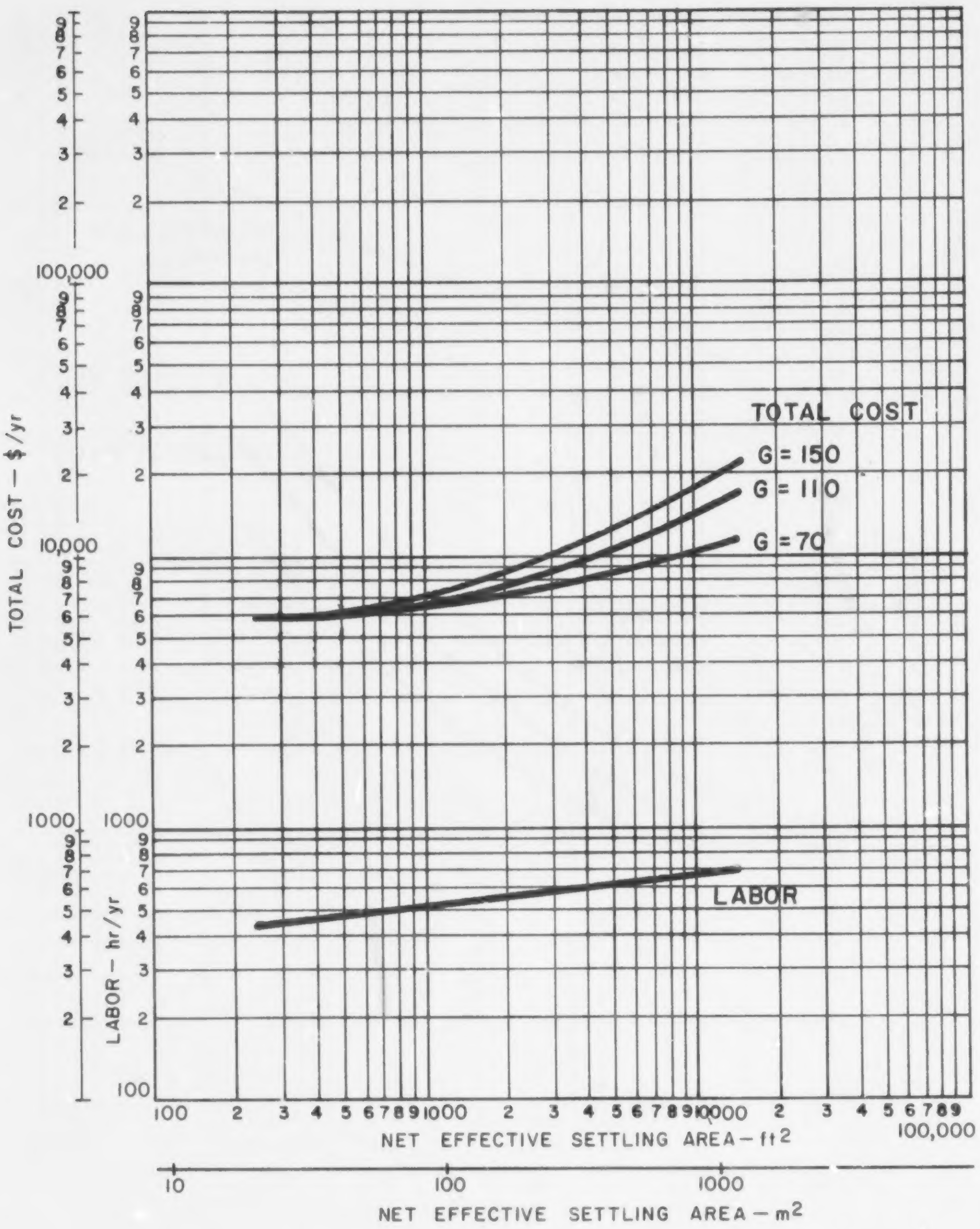


Figure 65. Operation and maintenance requirements for upflow solids contact clarifiers - labor and total cost.

Table 49
Operation and Maintenance Summary for Upflow Solids Contact Clarifiers

Clarifier Size		Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)		
Diameter (ft)	Net Effective Setting Area(ft^2)	G=70	G=110	G=150			G=70	G=110	G=150
20	255	8,170	8,170	13,070	$580	480	$5,630	$5,630	$5,770
30	643	11,440	14,700	24,510	650	480	5,790	5,890	6,190
45	1,457	17,970	37,580	44,110	900	571	7,150	7,740	7,930
60	2,544	26,140	45,740	71,880	1,080	571	7,570	8,160	8,950
80	4,455	42,480	75,150	140,500	1,440	571	8,420	9,400	11,370
125	10,370	84,950	182,980	346,350	2,070	662	11,240	14,180	19,080
150	14,544	130,700	294,070	424,770	2,340	662	12,880	17,780	21,700

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 50

Conceptual Design for
Tube Settling Modules

Plant Capacity (mgd)	Tube Module Area (ft^2)	Sedimentation Basin Area (ft^2)	Number of Sedimentation Basins	Basin Dimensions (ft)	
				Length	Width
1	280	350	2	18	10
10	2,800	3,500	2	60	30
50	14,000	17,500	2	110	80
100	28,000	35,000	2	220	80
200	56,000	70,000	4	220	80

Table 51

Construction Cost for

Tube Settling Modules

Cost Category	Tube Module Area (ft^2)				
	280	2,800	14,000	28,000	56,000
Manufactured Equipment	$ 4,200	$ 31,000	$ 147,000	$ 282,000	$ 504,000
Steel	2,000	19,500	95,000	155,000	300,000
Labor	2,500	11,200	49,000	95,000	224,000
SUBTOTAL	8,700	61,700	291,000	532,000	1,028,000
Miscellaneous & Contingency	1,300	9,260	43,650	79,800	154,200
TOTAL COST	10,000	70,960	334,650	611,800	1,182,200

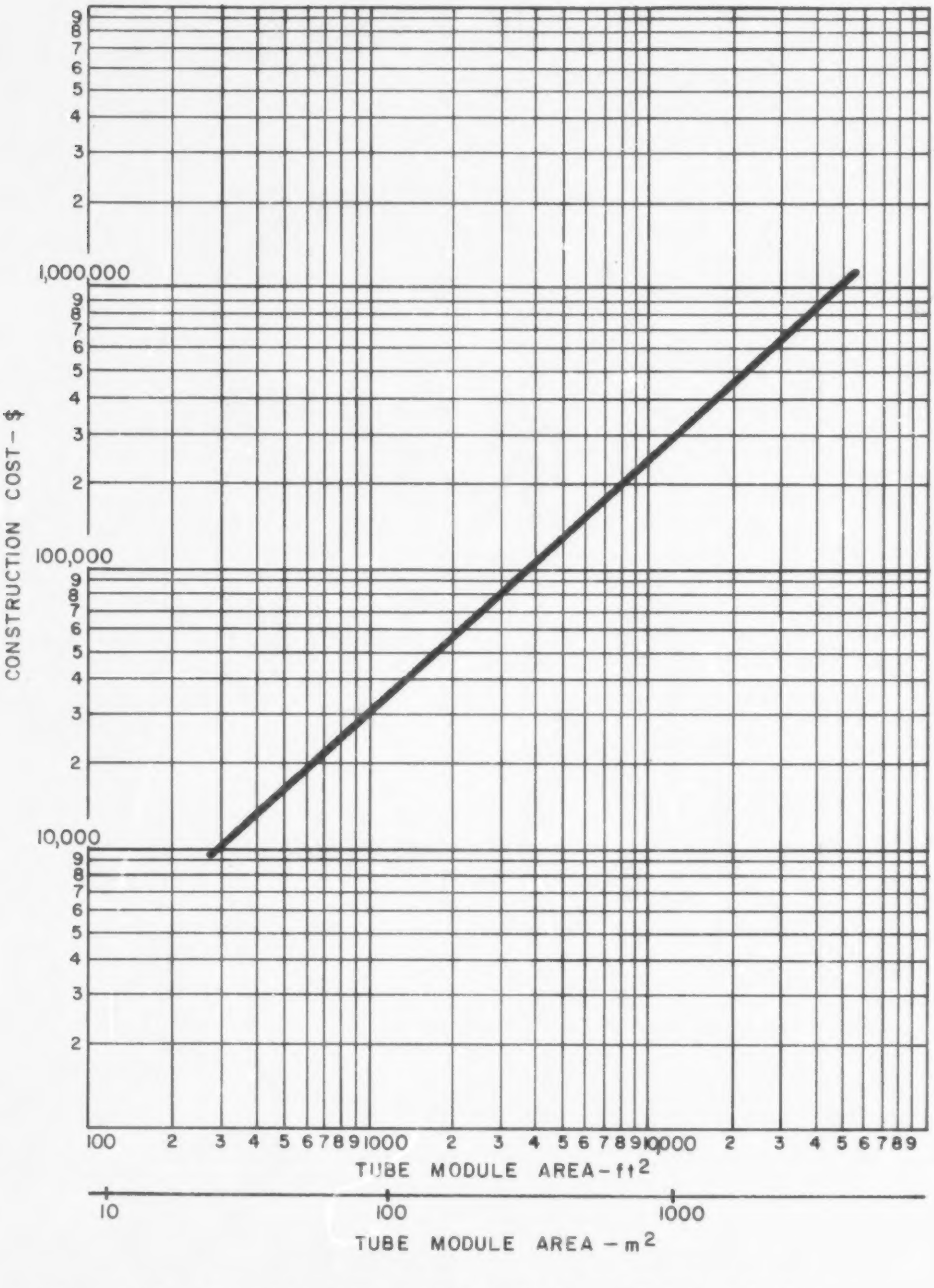


Figure 66. Construction cost for tube settling modules.

Table 52

Conceptual Designs for Gravity Filtration Structures

(24 to 36 Inch Media Depth)

Plant Flow (mgd)	Total Filter Area (ft^2)	Filters		Housing Requirement (ft^2)	
		Number	Area Each (ft^2)	Basic	Total
1	140	2	70	150	430
5	700	4	175	420	1,480
10	1,400	4	350	800	2,720
50	7,000	10	700*	2,900	11,600
100	14,000	14	1,000*	4,060	21,110
200	28,000	22	1,275*	6,380	40,190

*Dual-celled filters.

waste piping. On the designs up to and including 10 mgd, raw water was fed to the filter, using a gullet between the pipe gallery and the filter structure. Only one valve was used to admit raw water to the dual-celled filters, since the filters operate as one until the end of the filter cycle, even though they are backwashed separately. For designs up to and including 10 mgd, piping was used to convey product water in the pipe gallery, but larger designs used a covered concrete box structure in the center of the pipe gallery. Basic housing requirements include housing only the pipe gallery, which is located beneath the filter control area. The filter structure need not be housed except in severe winter climates, where other precautions such as diffused air addition near the filter periphery are not taken. The cost curves include, however, housing of the entire filter structure.

Costs for filtration structures are presented in Table 53 and Figure 67. These costs include the filter structure, underdrains, wash water troughs, a pipe gallery, required piping and cylinder operated butterfly valves, filter flow and headloss instrumentation, a filter control panel, and the total housing requirement. The costs do not include the cost of backwash water storage facilities, backwash pumping facilities, filtration media, or surface wash piping and pumps. These facilities were not included, since their use and sizing varies with each design, and they are most appropriately added separately.

Operation and Maintenance Cost

Energy requirements are only for building heating, ventilation, and lighting. All process energy required for filtration is included in the backwash and surface wash curves.

Maintenance material includes the cost of general supplies, instrumentation repair, and the periodic addition of filter media. Costs are based on costs experienced at several plants.

Labor costs include the cost of operation, as well as the cost of instrument and equipment repairs, and supervision.

Figures 68 and 69 present the operation and maintenance requirements, and Table 54 summarizes these requirements.

FILTRATION MEDIA

Construction Cost

Cost estimates have been prepared for three types of commonly used filtration media: rapid sand, dual media (coal-sand), and mixed media (coal-sand-garnet). The advantage of rapid sand medium is its low initial cost and simplicity of placement, whereas its disadvantages are the relatively low application rates and limited suspended solids loading. Though the more sophisticated dual and mixed media allow higher filtration rates and suspended solids loading than rapid sand, they are higher in initial cost and require in-place processing. Common practice is to backwash the media during placement and then to skim a shallow layer from the surface to remove excessive fines.

Table 53

Construction Cost for Gravity Filtration Structures

Cost Category	Total Filter Area (ft^2) and Plant Flow Rate (mgd)					
	140 ft^2 1 mgd	700 ft^2 5 mgd	1,400 ft^2 10 mgd	7,000 ft^2 50 mgd	14,000 ft^2 100 mgd	28,000 ft^2 200 mgd
Excavation & Sitework	$ 1,950	$ 3,620	$ 5,520	$ 16,220	$ 25,590	$ 43,410
Manufactured Equipment	26,360	56,960	78,300	305,170	529,360	982,390
Concrete	13,400	27,040	41,660	95,490	154,790	275,570
Steel	11,550	19,960	30,120	73,530	123,160	209,960
Labor	40,580	88,490	150,870	356,380	508,980	1,000,670
Pipe and Valves	20,580	79,020	127,340	420,670	590,150	1,125,500
Electrical & Instrumentation	13,390	38,410	38,410	99,140	168,840	265,310
Housing	17,400	40,480	70,590	291,940	514,330	968,520
SUBTOTAL	145,210	353,980	542,810	1,658,540	2,615,200	4,871,330
Miscellaneous & Contingency	21,780	53,100	81,420	248,780	392,280	730,700
TOTAL	166,990	407,080	624,230	1,907,320	3,007,480	5,602,030

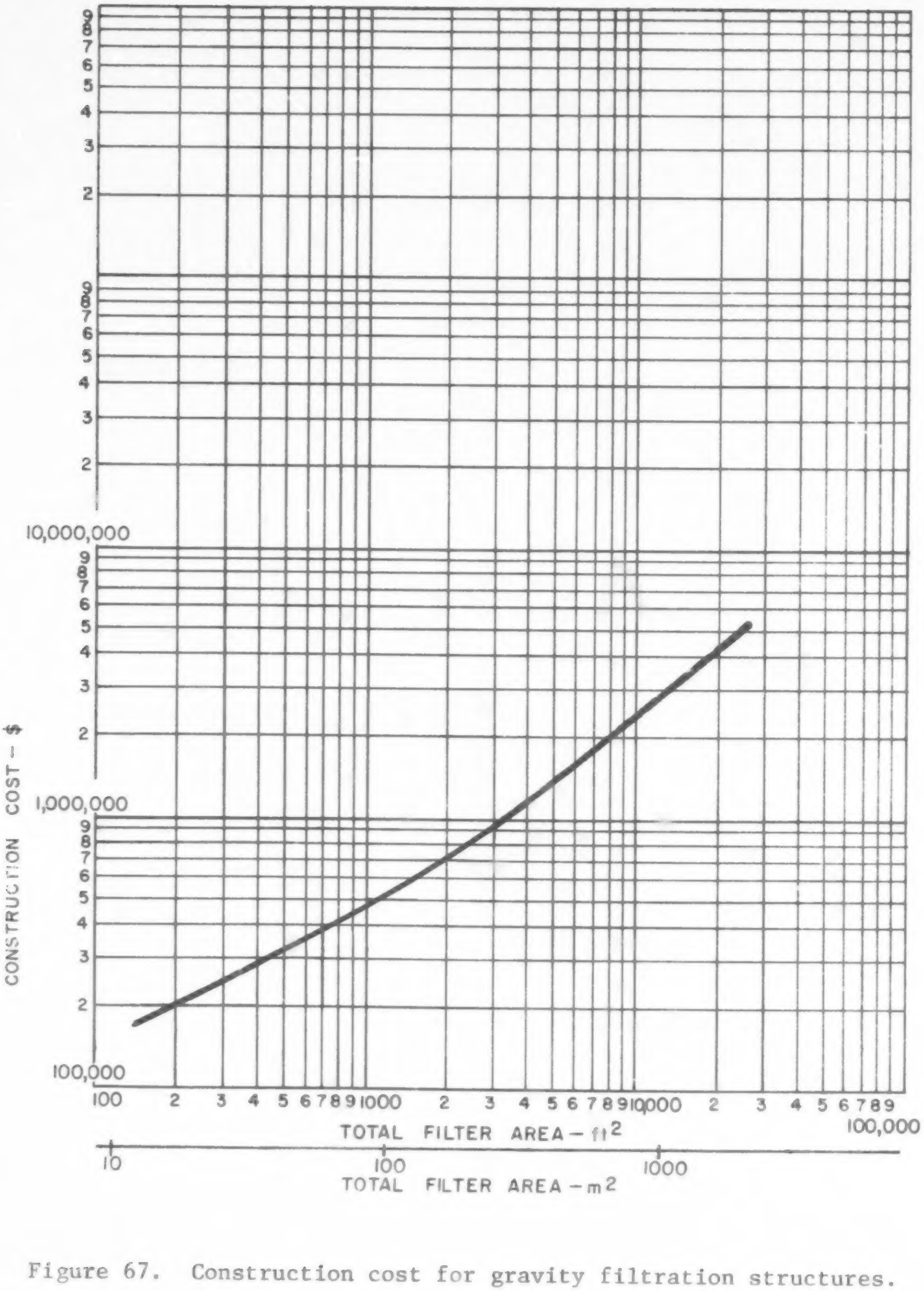


Figure 67. Construction cost for gravity filtration structures.

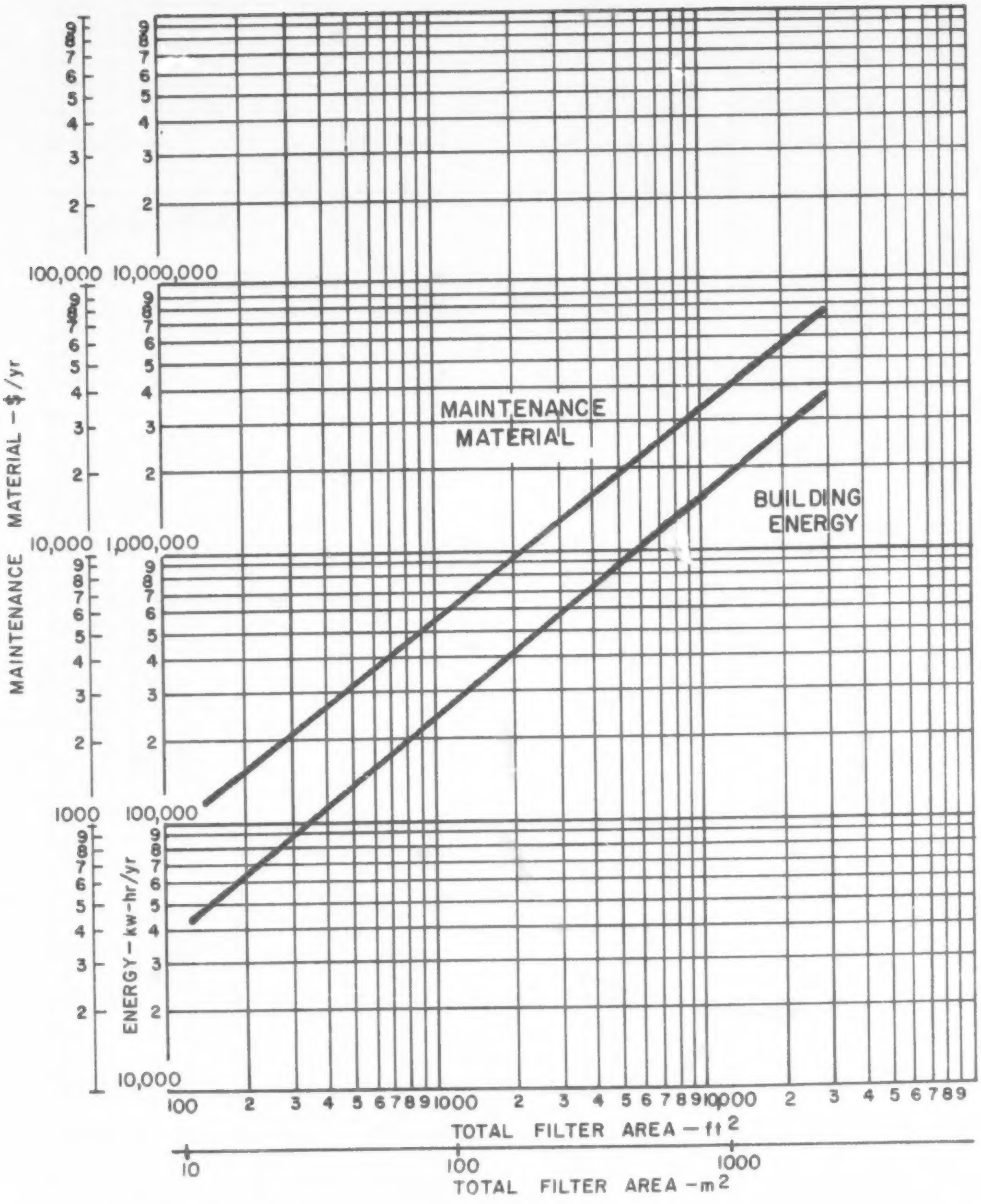


Figure 68. Operation and maintenance requirements for gravity filtration structures - building energy and maintenance material.

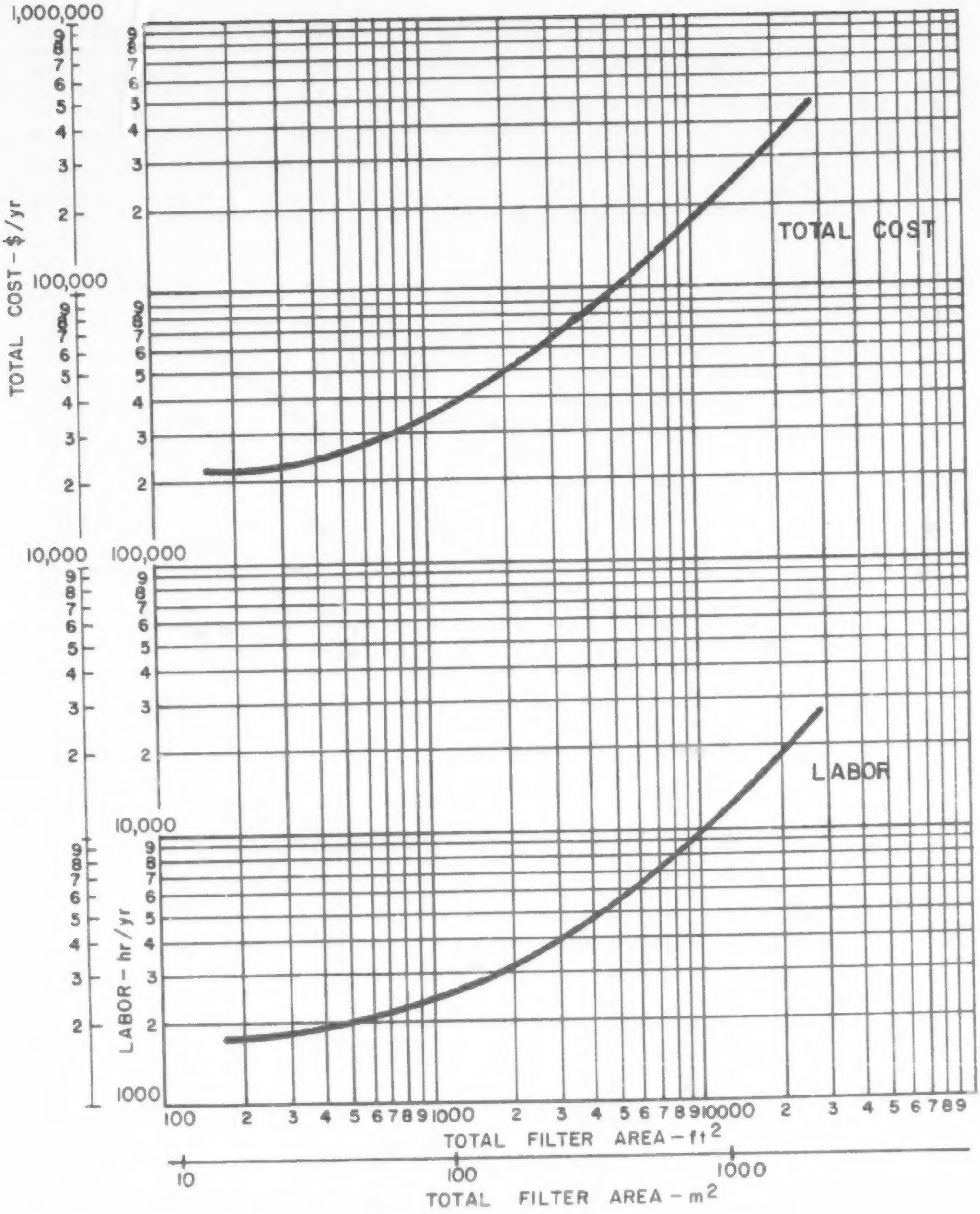


Figure 69. Operation and maintenance requirements for gravity filtration structures - labor and total cost.

Table 54

Operation and Maintenance Summary for Gravity Filtration Structures

Total Filter Area (ft^2)	Building Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
140	44,120	$ 800	900	$ 11,120
700	151,850	2,510	1,500	22,070
1,400	279,070	4,020	2,100	33,390
7,000	1,190,160	13,200	4,600	94,900
14,000	2,165,890	21,600	7,000	156,580
28,000	4,123,490	36,700	18,000	340,400

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Cost estimates have been made for purchase and placement of 30-in. of media over a 12-in. gravel underdrain. These estimates are applicable to either gravity or pressure filters, although pressure filters are often designed with a somewhat deeper gravel support layer. Characteristics of all three media and the gravel underdrain are presented in Table 55. Costs were developed as a function of filter area using a filtration rate of 2 gpm/ft^2 for rapid sand, and 5 gpm/ft^2 for dual media and mixed media. For plants with total filter areas of 140 ft^2 and less, materials were considered to be truck shipped in 100 lb bags. For total filter areas between 140 and 2,000 ft^2, rail shipment in 100 lb bags was assumed, and for larger filter areas, rail shipment by bulk was assumed.

The estimated costs include media cost, shipping, and installation. The cost of a trained technician to direct placement of the mixed media is also included. Freight cost represents a nationwide average. Estimated filtration media costs are presented in Figure 70 and Table 56.

BACKWASH PUMPING FACILITIES

Construction Cost

The cost of the backwash pumping system must be added to the basic cost for the filtration structure, filter media cost, surface wash, and any required backwash water storage capacity to arrive at the filtration facility cost. Included within the backwash pumping system cost is the cost of required pumps and motors, including one standby unit, flow control, filter backwash sequencing control, pump station valving, the backwash header cost not included in the filter structure, and motor starters. Backwash piping and valving was sized for a velocity of 7 ft/second. Housing costs are not included. The assumed pumping head for the backwash pump was 50 ft total dynamic head (TDH), and the maximum design rate for backwash was 18 gpm/ft^2. The largest pump utilized was 7,000 gpm, and one standby pump was included for all installations.

Construction cost estimates are shown by cost component on Table 57 and Figure 71. Costs are presented as a function of backwash pumping capacity, as the rate for any given size of filter will vary with the type of media utilized.

Operation and Maintenance Cost

Operation and maintenance curves are presented on the basis of total filter area. A backwash frequency of two per day with a 10-min duration per wash was assumed. For dual-cell filters, a backwash is defined as a backwash of both cells.

Energy requirements were calculated using a backwash rate of 15 gpm/ft^2, a pumping head of 50 ft TDH, and an overall motor/pump efficiency of 70 percent. Energy requirements are based on a backwash period of 10 min twice a day.

Table 55

Filter Media and Gravel Underdrain Characteristics

Item	Characteristics
Rapid Sand	30 in. of 0.42 to 0.55 mm effective size silica sand, uniformity coefficient less than 1.6
Dual Media	20 in. of 1.0 to 1.2 mm effective size anthracite coal, uniformity coefficient less than 1.7.
	10 in. of 0.42 to 0.55 mm effective size silica sand, uniformity coefficient less than 1.6
Mixed (Tri) Media	16.5 in. of 1.0 to 1.1 mm effective size anthracite coal, uniformity coefficient less than 1.7
	9 in. of 0.42 to 0.55 mm effective size silica sand, uniformity coefficient less than 1.6
	4.5 in. of 0.18 to 0.28 mm effective size garnet or ilmenite sand, uniformity coefficient less than 1.8
Gravel Underdrain (common to all media)	3 in. of 1-1/2" x 3/4" silica gravel 3 in. of 3/4" x 3/8" silica gravel 3 in. of 3/8" x 3/16" silica gravel 3 in. of 3/16" x #10 silica gravel

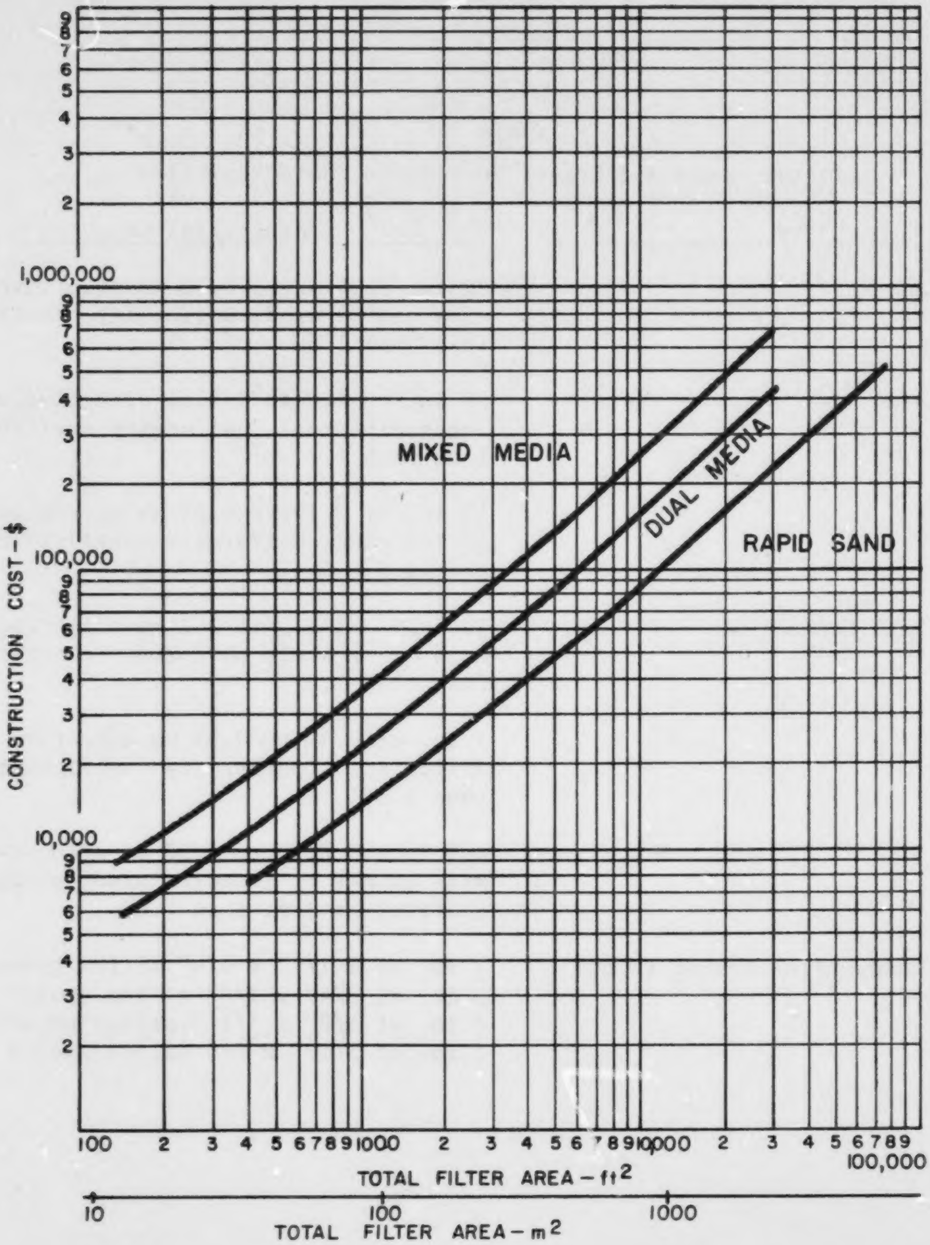


Figure 70. Construction cost for filtration media.

Table 56

Construction Cost for Filtration Media

Plant Capacity (mgd)	Filter Bed Area (ft^2)		Filter Media Costs Installed		
	Rapid Sand	Dual and Mixed Media	Rapid Sand	Dual Media	Mixed Media
1	350	140	$ 6,500	$ 5,800	$ 9,000
5	1,750	700	26,270	18,160	25,720
10	3,500	1,400	29,070	33,030	48,860
50	17,500	7,000	140,570	113,950	181,410
100	35,000	14,000	280,320	217,400	355,530
200	70,000	28,000	559,800	431,280	699,780

Table 57

Construction Cost for

Backwash Pumping Facilities

Cost Category	Pumping Capacity , mgd (gpm)				
	1,260 (1.8)	3,150 (4.5)	6,300 (9.1)	18,000 (25.9)	22,950 (33)
Manufactured Equipment	$11,400	$ 14,600	$ 38,380	$ 76,780	$ 95,970
Labor	3,050	4,410	4,880	9,290	12,440
Pipe and Valves	9,780	17,690	17,690	33,390	44,780
Electrical and Instrumentation	13,350	16,040	16,740	28,070	33,250
SUBTOTAL	37,580	52,740	77,690	147,530	186,440
Miscellaneous and Contingency	5,640	7,910	11,650	22,130	27,970
TOTAL	43,220	60,650	89,340	169,660	214,410

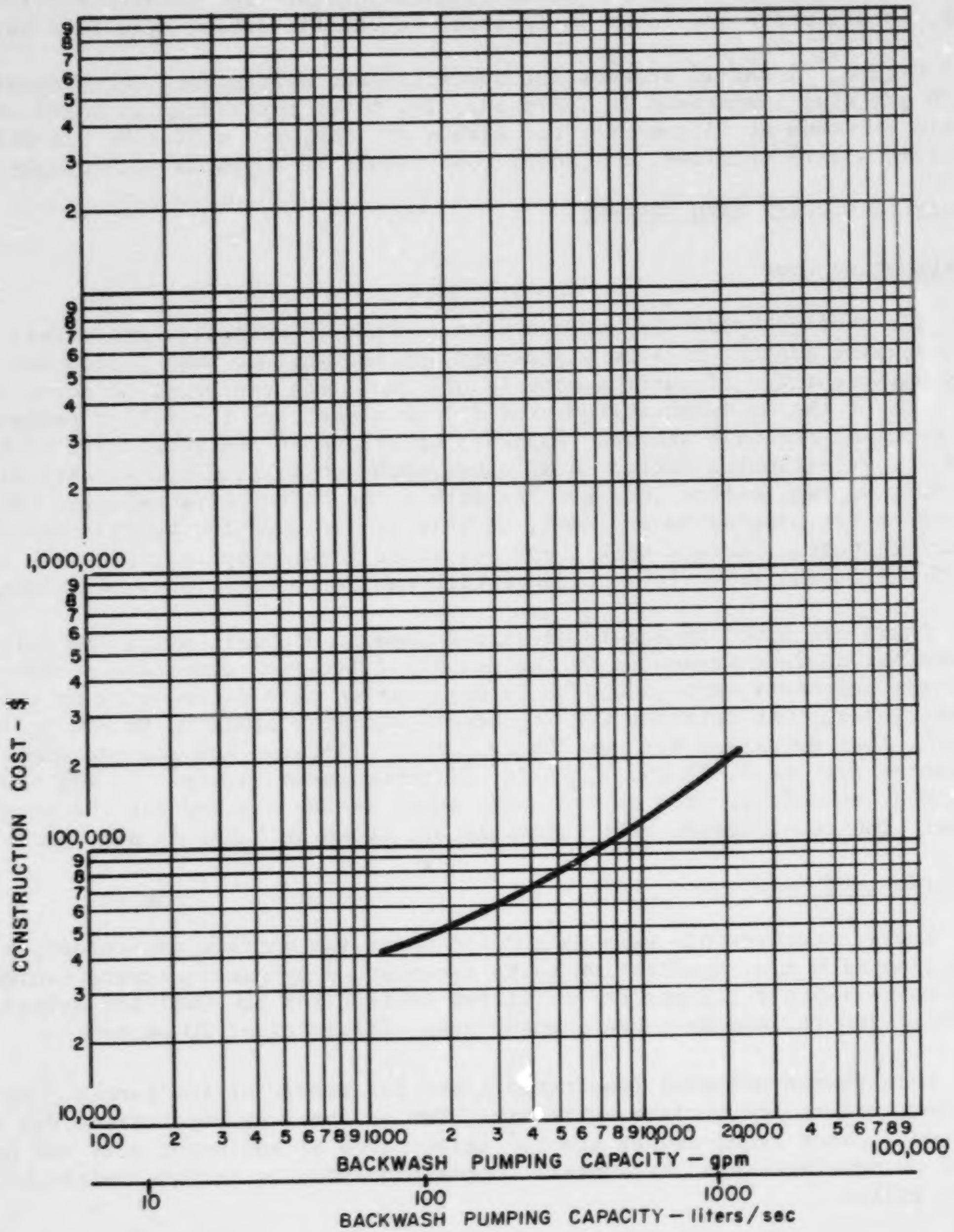


Figure 71. Construction cost for backwash pumping facilities.

Maintenance material costs are for repair of the backwash pumps, the motor starters, and valving. Labor requirements are for maintenance labor only, as all operation labor is included in the filtration structure curve.

Figures 72 and 73 present the operation and maintenance requirements, which are also summarized in Table 58. The total cost curve is based on a 10 min backwash at 15 gpm/ft^2, two washes per day, and a 50 TDH. If different conditions were utilized, the total cost should be adjusted accordingly.

HYDRAULIC SURFACE WASH SYSTEMS

Construction Cost

The cost of hydraulic surface wash systems is presented separately from the backwash system, as some plants may not use surface wash in conjunction with backwashing. If surface wash is utilized, the cost must be added to the cost of the backwash system, the filter structure, the filter media, and any required backwash storage capacity to arrive at the total cost of filtration. Cost estimates include dual pumps with one as standby, electrical control, piping, valves, and headers within the filter pipe gallery. No allowance for housing is included, as this is included in the filtration structure cost. Surface wash pumps are sized to provide approximately 50 to 85 psi at the arms, in accordance with manufacturers' recommendations.

Costs are based on the total filter area of a plant, using the filter conceptual designs presented in the gravity filtration structure section. Dual-arm agitators were used with an application rate recommended by the manufacturer. One agitator was included for filter areas up to and including 75 ft^2, four agitators for the 350 to 700 ft^2 filters, and six and eight agitators for the 1,000 and 1,275 ft^2 filters, respectively. It was assumed that the wet well for the surface wash pumps is the same as for the backwash pumps. The construction cost estimates are shown in Table 59 and Figure 74.

Operation and Maintenance Cost

Energy requirements were calculated using two surface washes/day, a wash time of 8 min, application rates recommended by manufacturers (which were approximately 1.5 gpm/ft^2 of filter surface for the dual-arm agitators), a TDH of 200 ft, and an overall motor pump efficiency of 70 percent.

Maintenance material requirements are for repair of the pump(s), motor starter, valves and .surface agitators. Two surface wash operations/day were assumed. Labor requirements are for maintenance of equipment only and are based on manufacturers' estimates. Operation labor is included with the basic filter.

Figures 75 and 76 present the operation and maintenance requirements for hydraulic surface wash systems. The total cost must be added to the costs for filter backwashing and filter operation to arrive at the total operation and maintenance cost for filter operation. An operation and maintenance summary for hydraulic surface wash systems is presented in Table 60.

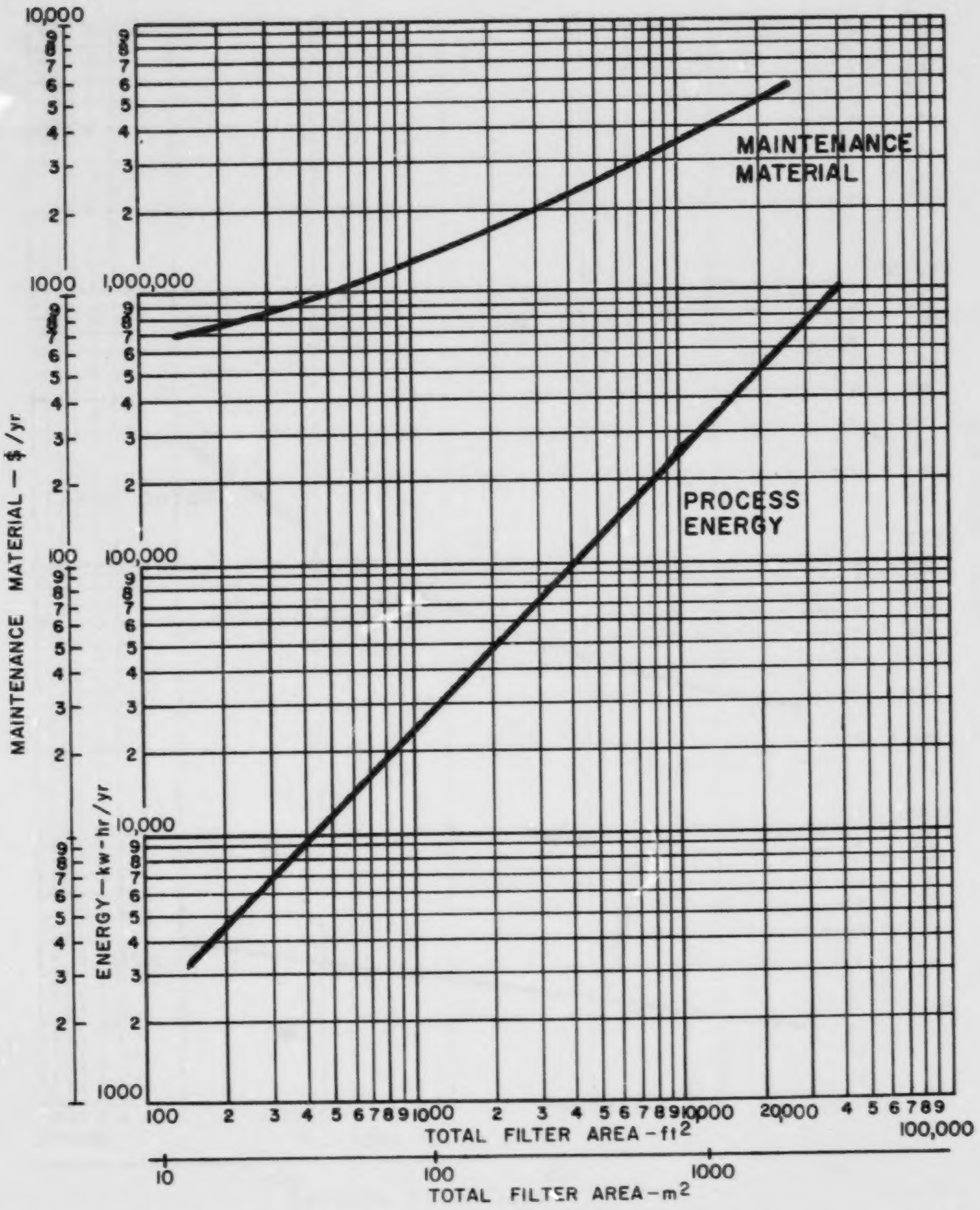


Figure 72. Operation and maintenance requirements for backwash pumping facilities - process energy and maintenance material.

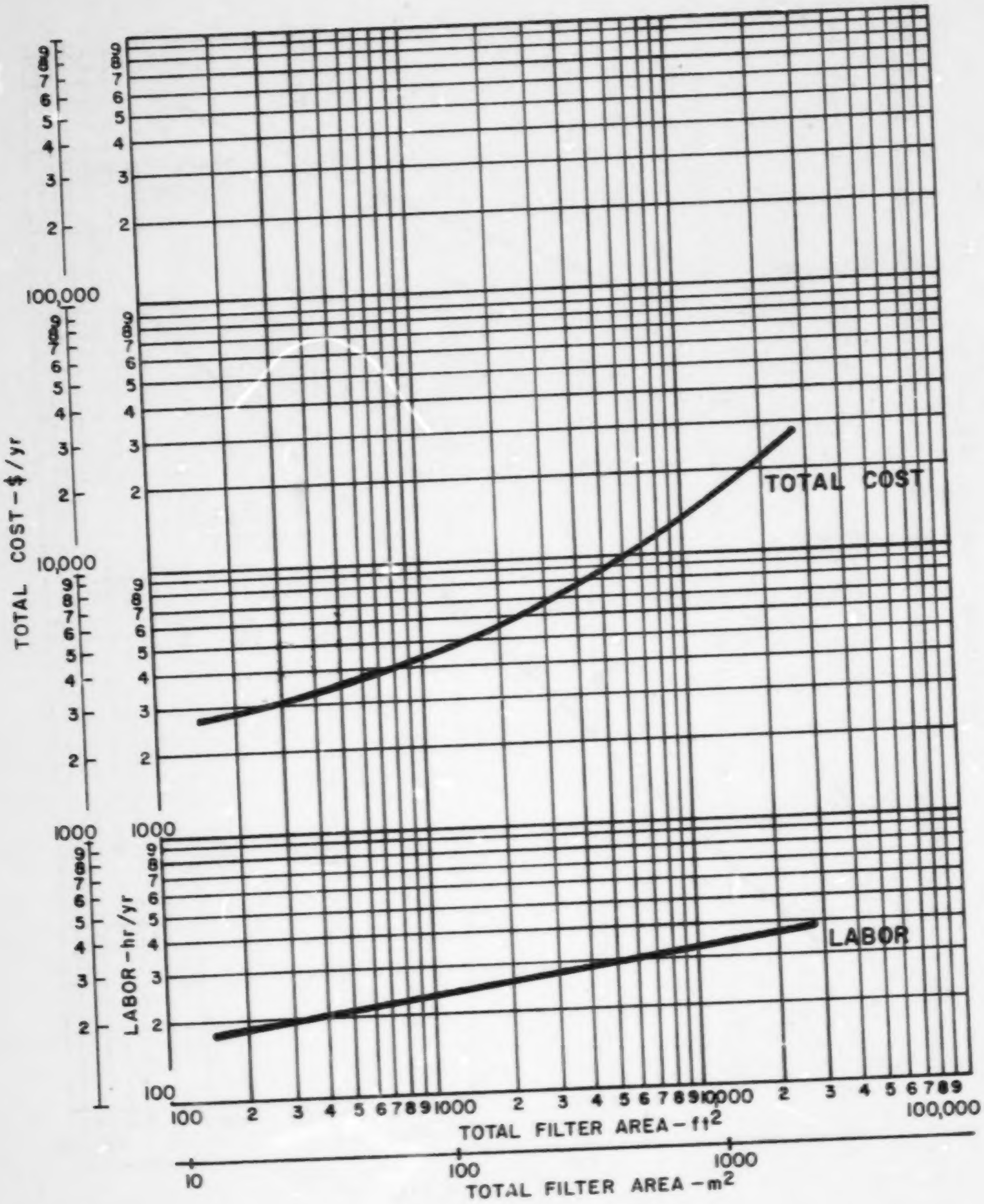


Figure 73. Operation and maintenance requirements for backwash pumping facilities - labor and total cost.

Table 58

Operation and Maintenance Summary for Backwash Pumping Facilities

Total Filter Area (ft^2)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
140	3,340	$ 700	190	$ 2,700
700	16,720	1,100	210	3,700
1,400	33,440	1,800	250	5,300
7,000	167,240	3,400	300	11,420
14,000	334,460	4,200	350	17,730
28,000	670,120	5,700	370	29,500

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 59

Construction Cost for

Hydraulic Surface Wash Systems

Cost Category	Total Filter Area (ft^2)					
	140	700	1,400	7,000	14,000	28,000
Manufactured Equipment	$ 9,170	$12,050	$35,090	$82,010	$172,440	$401,200
Labor	1,300	2,770	5,170	14,710	29,430	66,600
Pipe and Valves	2,570	5,100	7,020	13,390	32,290	59,870
Electrical and Instrumentation	12,670	17,920	20,440	37,900	61,120	92,360
SUBTOTAL	25,710	37,840	67,720	148,010	295,280	620,030
Miscellaneous and Contingency	3,860	5,680	10,160	22,200	44,290	93,000
TOTAL	29,570	43,520	77,880	170,210	339,570	713,030

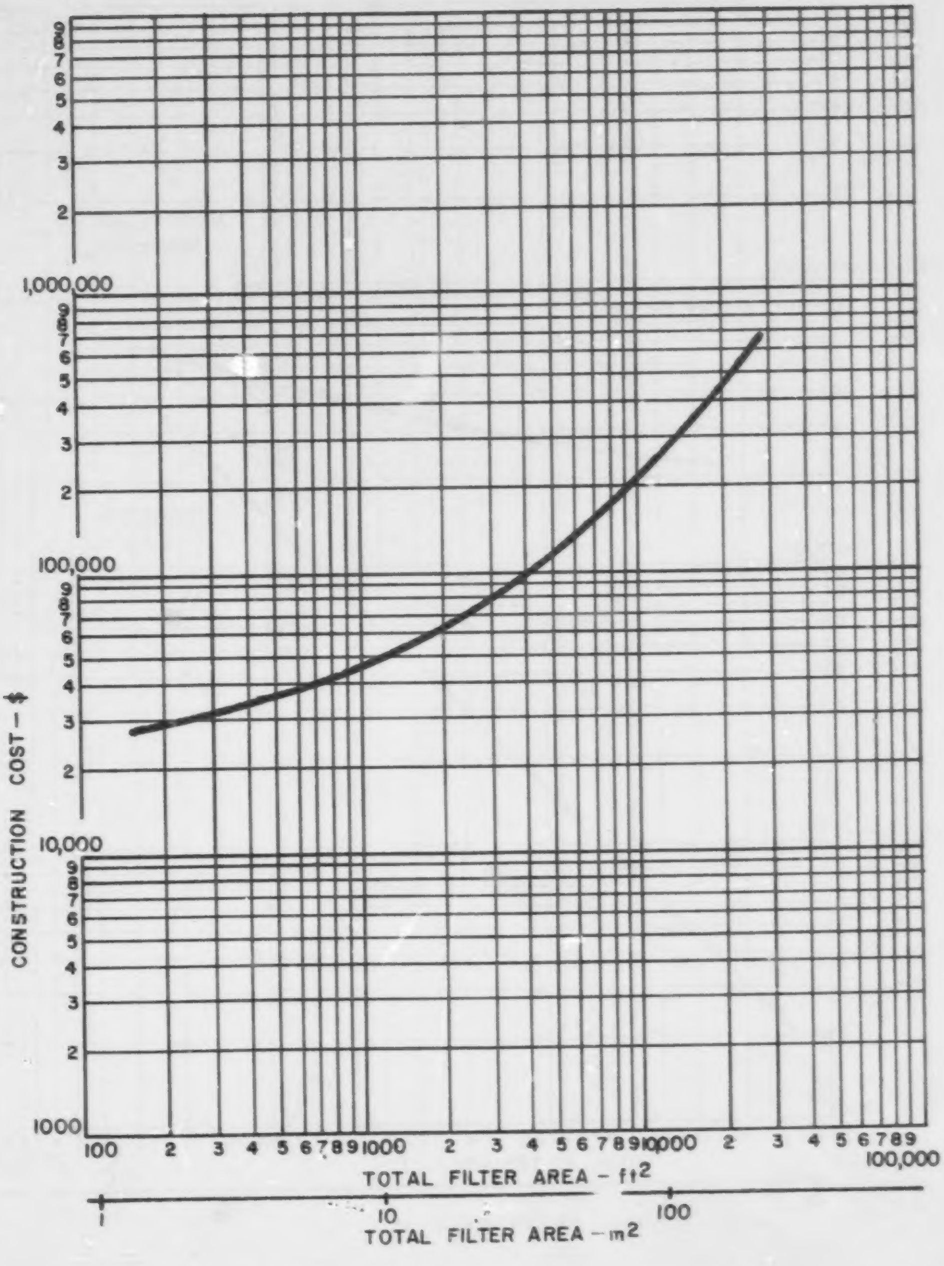


Figure 74. Construction cost for hydraulic surface wash systems.

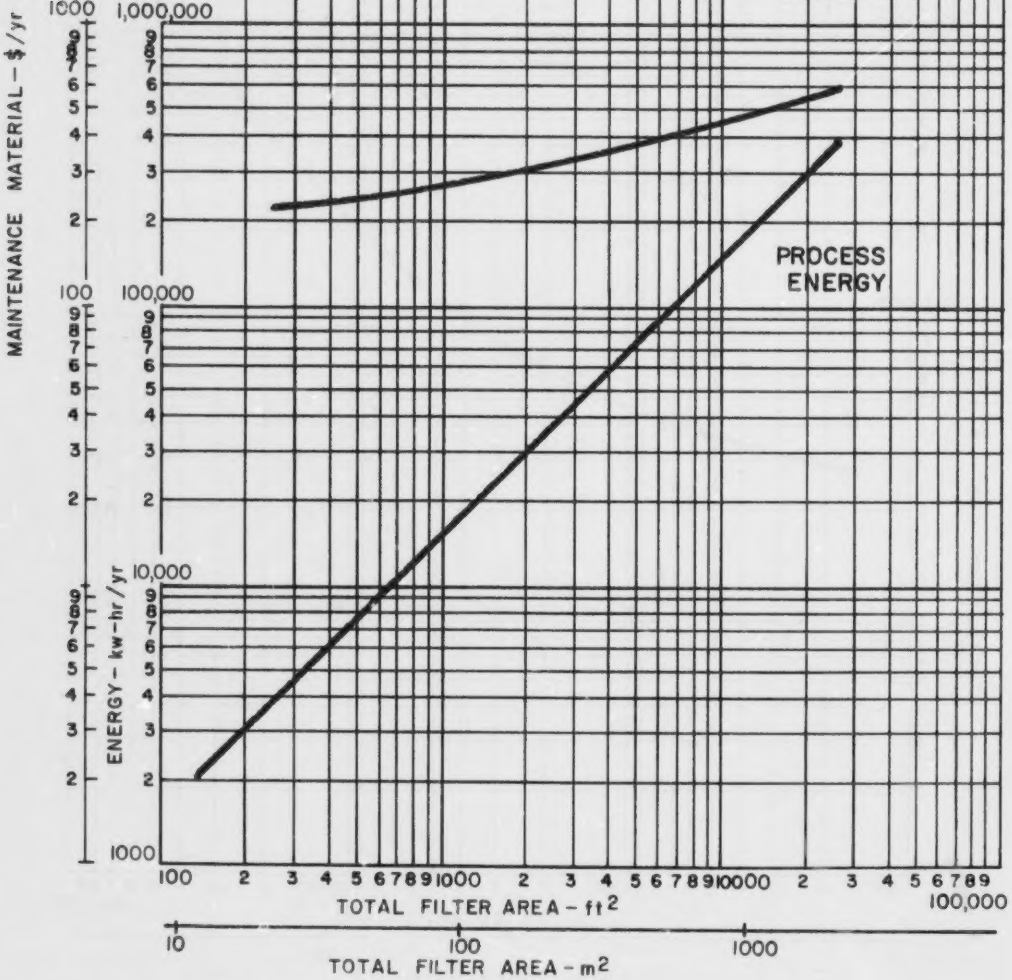


Figure 75. Operation and maintenance requirements for hydraulic surface wash systems - process energy and maintenance material.

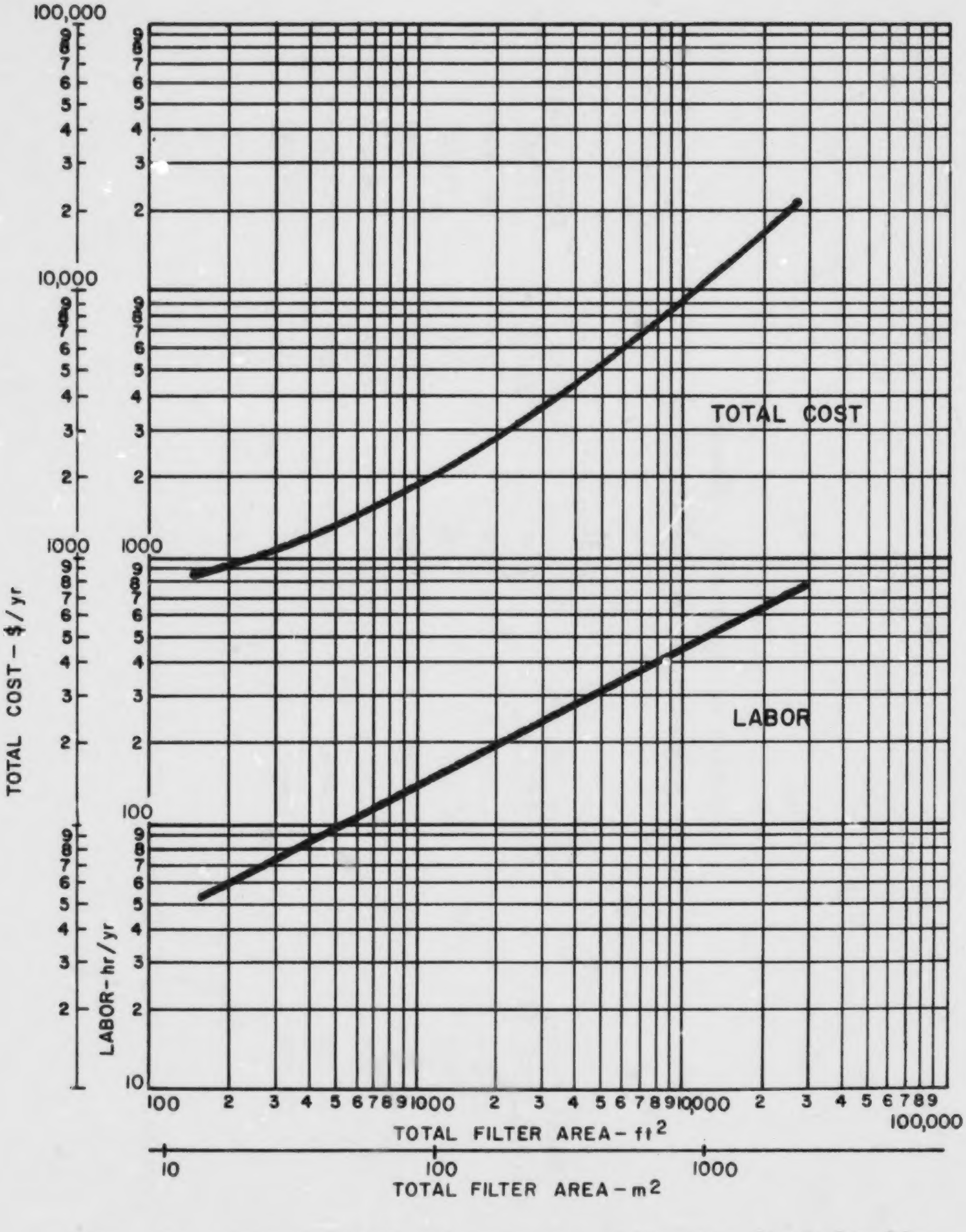


Figure 76. Operation and maintenance requirements for hydraulic surface wash systems - labor and total cost.

Table 60

Operation and Maintenance Summary for Hydraulic Surface Wash Systems

Total Filter Surface Area (ft^2)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
140	2,310	$200	54	$ 810
700	9,640	250	118	1,720
1,400	22,020	300	202	2,980
7,000	90,300	400	310	6,210
14,000	202,460	500	398	10,550
28,000	397,490	600	812	20,640

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

AIR-WATER BACKWASH FACILITIES

Construction Cost

The introduction of air into the filter underdrains before backwash is a concept that was developed to reduce the quantity of wash water utilized. The air is introduced first to scour material from the filter bed, and then backwash is used to restratify the filter bed. Although a different type of underdrain is required for air-water backwash than for conventional wash, the costs for the two types of underdrains are comparable.

The cost estimates that were developed are for both the air supply and water supply components of the backwash system. The air compressor and motor drives, backwash pumps and motor drives, filter backwash sequencing control, the air supply header and piping to the filters, the wash water piping outside of the basic filter structure, and all required valving and electrical equipment and instrumentation are included in the cost estimate. One standby air compressor and backwash pump is included for each installation. Facilities were sized based on air flow of 5 cfm/ft^2 of filter area at 8 psi and a maximum wash rate of 18 gpm/ft^2 of filter area. No allowance was included for housing, since housing costs were included with the basic filter structure.

The construction cost for the air-water backwash facilities is shown in Table 61 and Figure 77.

Operation and Maintenance Cost

The operation and maintenance costs are a composite of the air system costs and the backwash system costs. Costs were calculated based on 5 min of air addition per backwash at a rate of 5 cfm/ft^2 and a pressure of 8 psi, followed by a backwash of 5 min at a rate of 15 gpm/ft^2 Process energy costs are based on two backwashes/day per filter.

Labor and maintenance material requirements are essentially the same as for water backwash systems.

Figures 78 and 79 show the operation and maintenance requirements for air-water backwash systems. A summary of these requirements is presented in Table 62.

WASH WATER SURGE BASINS

Construction Cost

When filter wash water is recycled through the plant, treated in a separate plant, or discharged to a sanitary sewer, a surge basin may be used to even out the flow. Construction costs were developed for covered, below-ground, reinforced concrete basins. Level control instrumentation is included in the cost estimates. The cost for pumping facilities to return water for treatment or to pump it to a sewer are not included. Construction costs for wash water surge basins are shown in Table 63 and Figure 80.

Table 61

Construction Cost for
Air-Water Backwash Facilities

Cost Category	Total Filter Area (ft^2)					
	140	700	1,400	7,000	14,000	28,000
Manufactured Equipment	$26,520	$ 34,330	$ 66,100	$ 70,060	$ 121,000	$ 147,440
Labor	5,350	9,060	11,620	20,120	32,160	50,590
Pipe and Valves	13,910	30,970	48,780	93,700	162,240	323,000
Electrical & Instrumentation	14,250	16,820	17,490	18,190	29,010	34,560
SUBTOTAL	60,030	91,180	143,990	202,070	344,410	555,590
Miscellaneous & Contingency	9,000	13,680	21,600	30,310	51,660	83,340
TOTAL	69,030	104,860	165,590	232,380	396,070	638,930

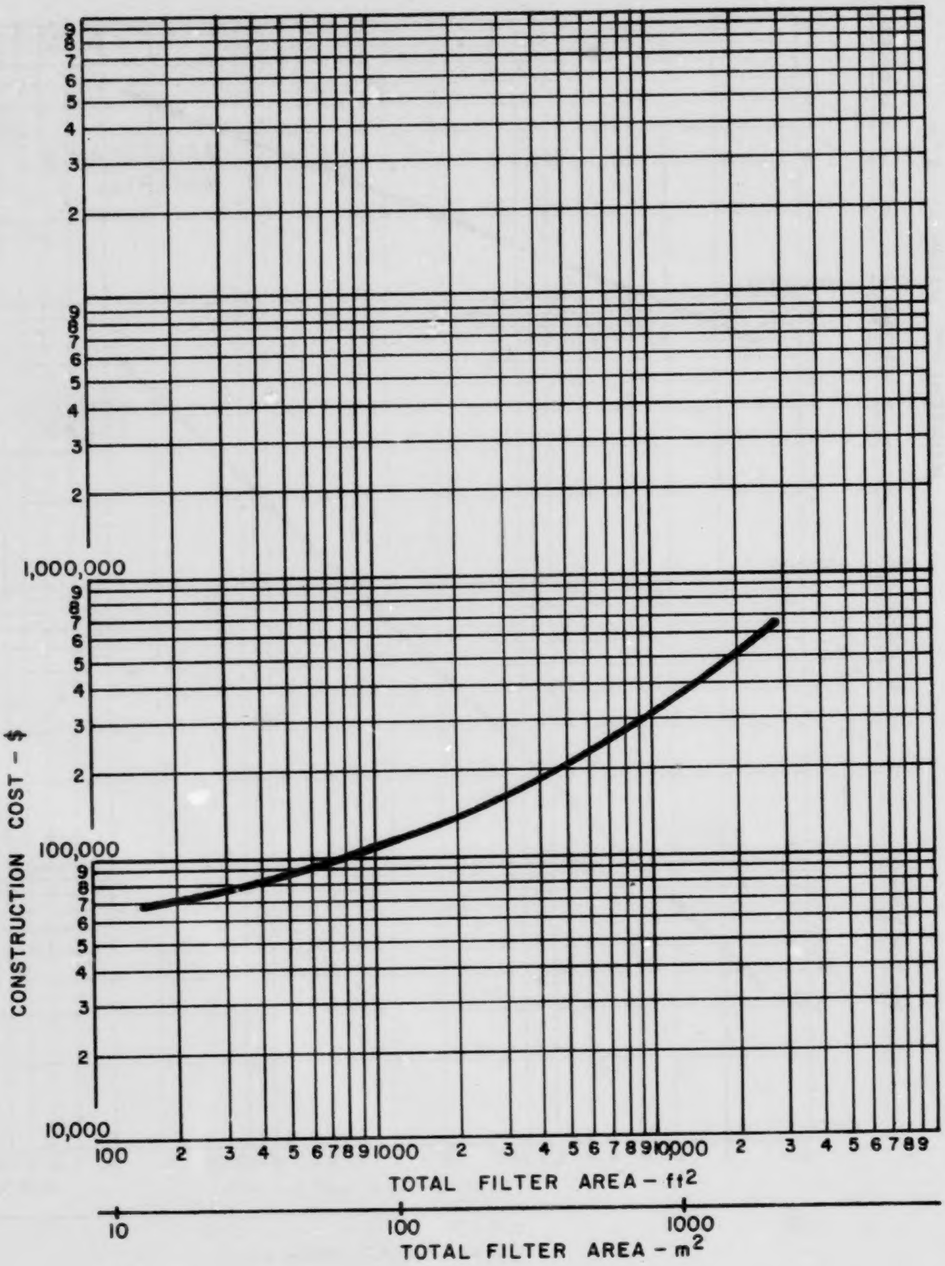


Figure 77. Construction cost for air-water backwash facilities.

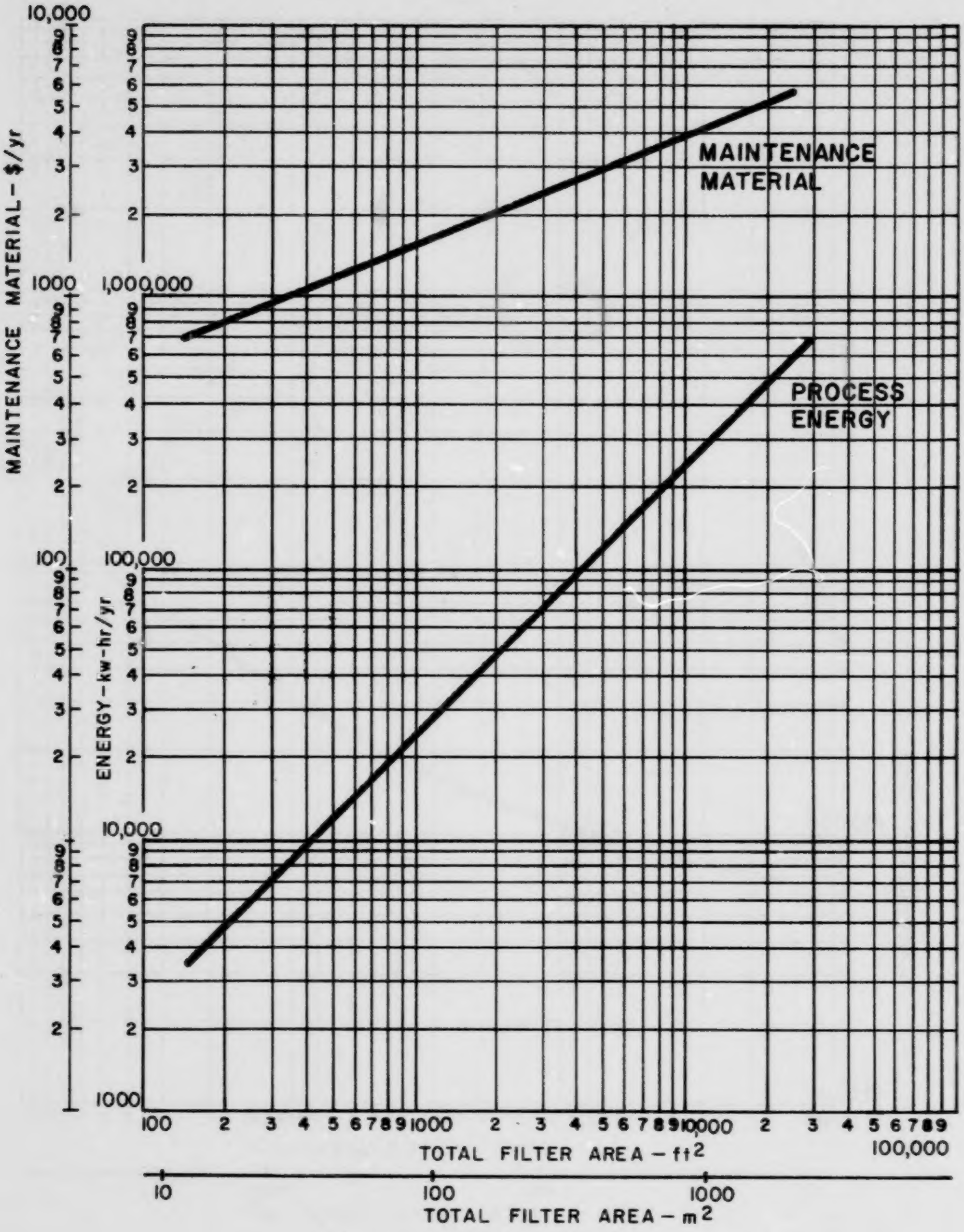


Figure 78. Operation and maintenance requirements for air-water backwash facilities - process energy and maintenance material.

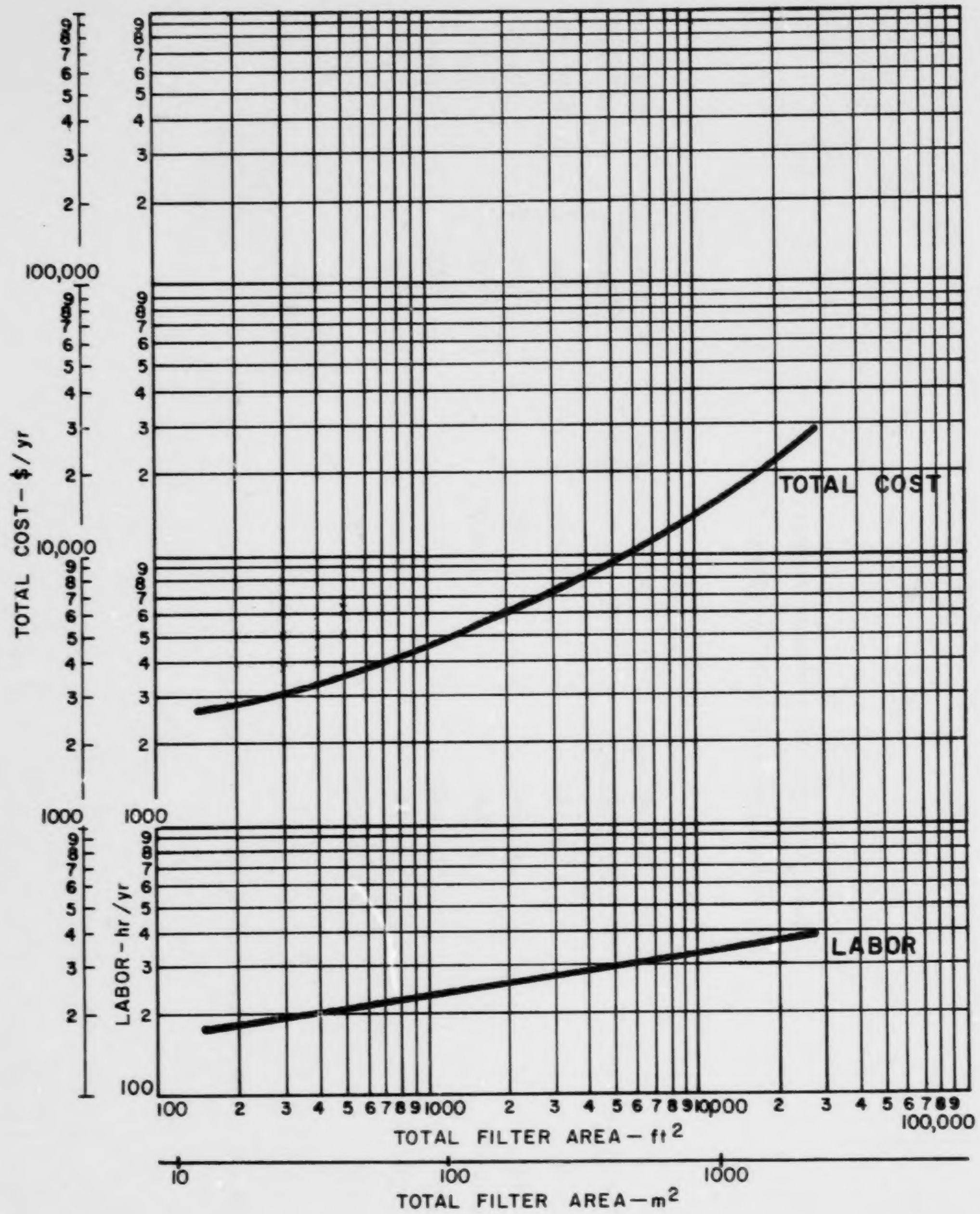


Figure 79. Operation and maintenance requirements for air-water backwash facilities - labor and total cost.

Table 62

Operation and Maintenance Summary
for Air-Water Backwash Facilities

Total Filter Area (ft^2)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
140	3,390	$ 700	190	$ 2,700
700	16,920	1,100	210	3,710
1,400	33,890	1,800	250	5,320
7,000	169,440	3,400	300	11,480
14,000	338,950	4,200	350	17,870
28,000	679,160	5,700	370	29,770

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 63

Construction Cost for
Wash Water Surge Basins

Cost Category	Basin Capacity (gal) 10,000	50,000	100,000	500,000
Excavation and Sitework	$ 200	$ 520	$ 1,250	$ 4,400
Concrete	11,560	39,310	71,480	143,680
Steel	7,990	25,170	44,680	70,770
Labor	18,270	58,500	107,590	182,150
Pipe and Valves	5,500	7,500	11,000	16,000
Electrical & Instrumentation	1,300	1,300	6,000	6,000
SUBTOTAL	44,820	132,300	242,000	423,000
Miscellaneous and Contingency	6,720	19,850	36,300	63,450
TOTAL	51,540	152,150	278,300	486,450

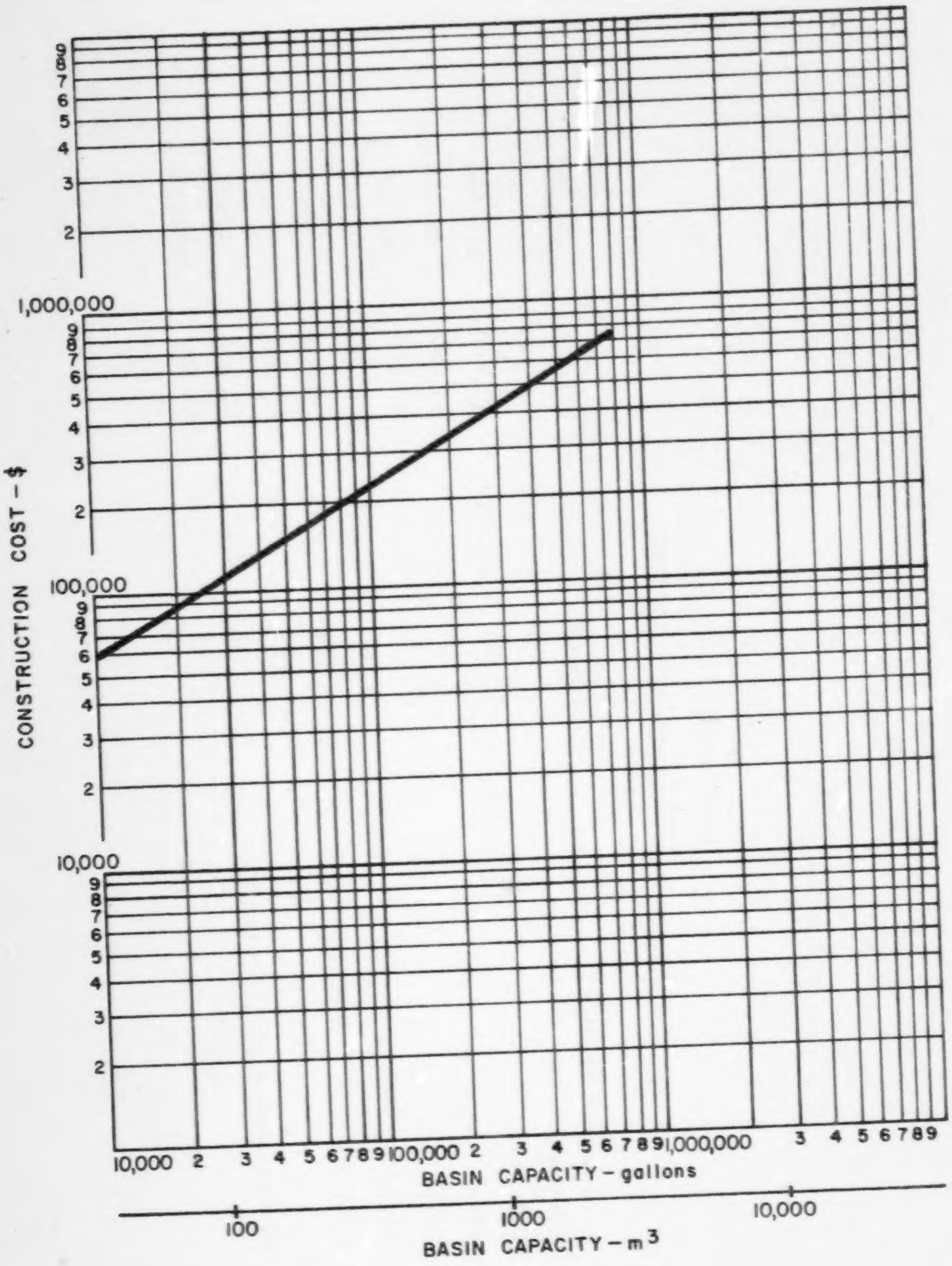


Figure 80. Construction cost for wash water surge basins.

MODIFICATION OF RAPID SAND FILTERS TO HIGH-RATE FILTERS

Construction Cost

Many existing rapid sand filtration plants originally designed with a filtration rate of 2 gpm/ft^2 can be upgraded to high-rate filtration (4 to 5 gpm/ft^2 filtration rates) without requiring structural modifications. The upgrading involves removal of existing sand media and underdrain gravel, replacement of effluent piping and flow control devices with larger piping and a new rate of flow controller, and installation of mixed or dual-media materials.

Costs were developed for accomplishing these modifications for plants with total filtration bed areas ranging from 140 to 28,000 ft^2. Filter sizes and configurations for which costs were developed are the same as those used in the gravity filtration structure curve. Included is the cost of removing sand and gravel, and hauling it to disposal on the plant site. It was assumed that the existing filter bottom would be compatible with the new filtration system and would be retained unchanged. It is also assumed that the existing backwash system will provide a minimum wash rate of 15 gpm/ft^2. The costs include new effluent piping, a new, pneumatically operated butterfly valve, and a rate of flow controller mounted in existing filter control consoles.

Costs for accomplishing these modifications are presented in Table 64 and Figure 81. Filtration media costs must also be added to these costs to obtain the total cost for conversion to high-rate filtration.

CONTINUOUS AUTOMATIC BACKWASH FILTERS

Construction Cost

The continuous automatic backwash filter is an adaptation of rapid sand filtration principles. The filter bed is contained in a shallow rectangular concrete structure that is laterally divided into compartments. Each compartment is, in effect, a single filter. Filter flow rate is based on declining rate, as there are no rate-of-flow controllers. An attractive feature of the filter is that operating head losses are generally less than 1 ft of water. A motor driven carriage assembly equipped with a backwash pump and a washwater collection pump backwashes each compartment sequentially as it traverses the length of the filter.

Costs were developed for filter units capable of handling flows from 1 to 200 mgd at a filtration rate of 2 gpm/ft^2. Conceptual designs are listed in Table 65. A filter box depth of 5 ft was used for all sizes of filters, and each size of plant utilizes a minimum of two filters. The filter units are essentially self-contained and require no interconnecting piping. Filtered water, influent, and backwash water are conducted to and from the filter by troughs or channels integrally cast within the concrete filter structure.

Table 64

Construction Cost for

Modification of Rapid Sand Filters to High Rate Filters

Cost Category	Total Filter Area (ft^2) 140	700	1,400	7,000	14,000	28,000
Labor	$8,600	$11,140	$23,900	$58,400	$91,700	$157,300
Pipe & Valves	8,940	17,400	23,000	78,000	143,000	260,000
Electrical & Instrumentation	3,900	8,500	12,200	20,000	28,000	46,000
SUBTOTAL	21,440	37,040	59,100	156,400	262,700	463,300
Miscellaneous & Contingency	3,220	5,560	8,870	23,460	39,400	69,500
TOTAL COST	24,660	42,600	67,970	179,860	302,100	532,800

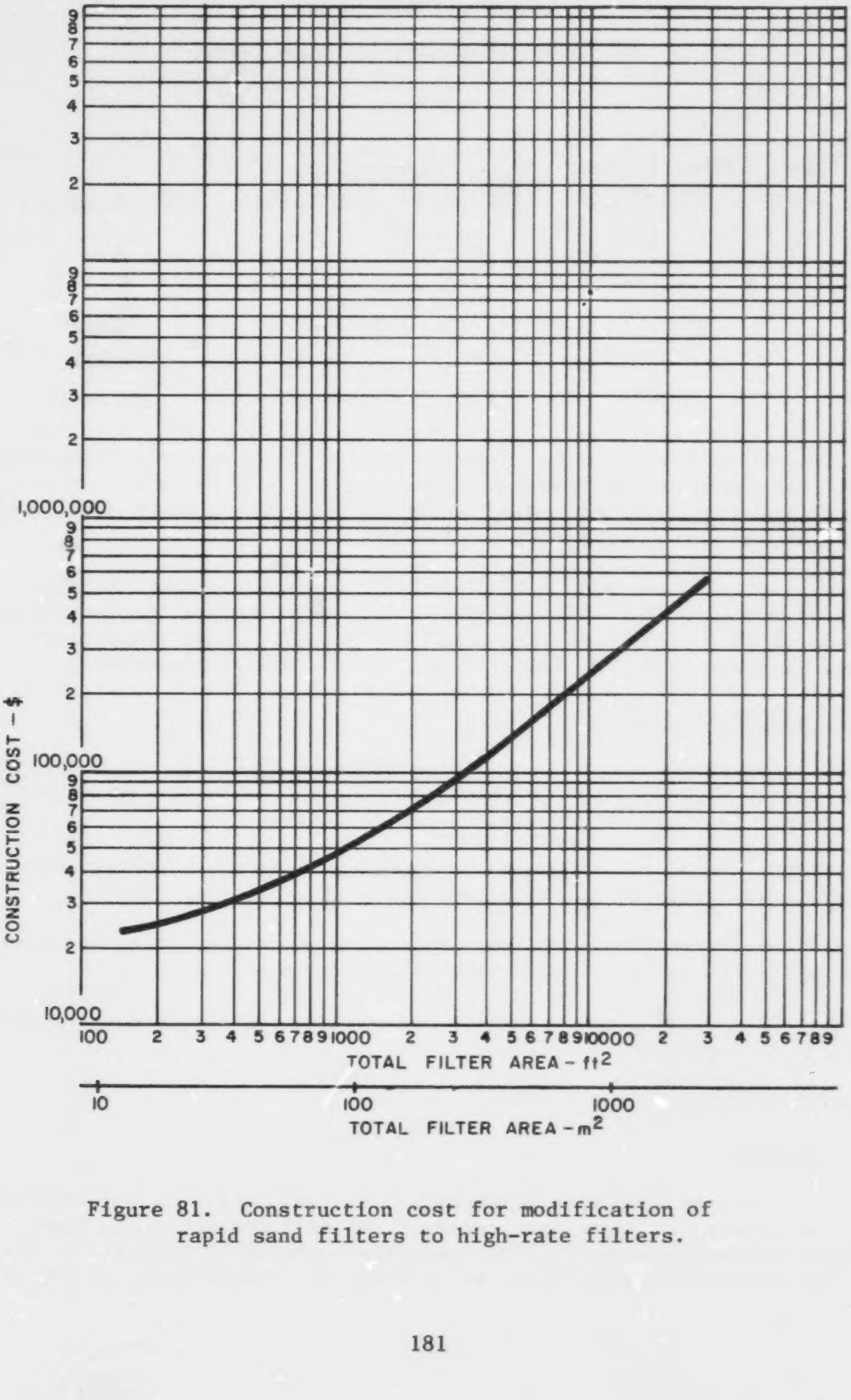


Figure 81. Construction cost for modification of rapid sand filters to high-rate filters.

Table 65

Conceptual Design for

Continuous Automatic Backwash Filter

Plant Flow mgd	Total Filter Area (ft^2)	Filters		Housing (ft^2)
		Number	Area (ft^2)	
1	360	2	180	1,088
5	1,750	2	875	3,332
10	3,520	2	1,760	6,120
100	35,200	20	1,760	81,600
200	70,400	40	1,760	162,625

The nature of the equipment requires that it be housed for protection from inclement weather and freezing temperatures. Housing costs were developed, assuming total enclosure of the filters with minimum additional space for access on two of the four sides for maintenance.

The costs are presented in Table 66 and Figure 82 and include the filtration structure, internal mechanical equipment, partitions, underdrains, rapid sand filter media (depth generally 11 in.) wash water collection trough, over-head pump carriage, electrical controls, and instrumentation.

Operation and Maintenance Cost

Energy requirements are for building heating, lighting, and ventilation and for pumping costs related to backwashing of the automatic backwash filter. It was assumed that the entire filter unit is housed.

Maintenance material costs include general supplies, pump maintenance and repair parts, replacement sand, and other miscellaneous items.

Labor costs were estimated from projected maintenance time requirements and are related to general supervision and maintenance.

Table 67 summarizes the operation and maintenance requirements, which are illustrated in Figures 83 and 84.

RECARBONATION BASINS

Construction Cost

Costs were developed for recarbonation basins, including the reinforced concrete structure, complete with influent and effluent channels, foam supression piping and sprayers, and handrails surrounding the basin. CO_2 gaseous or liquid CO_2 is utilized, as well as the concentration of CO_2 in the

Table 66

Construction Cost for
Continuous Automatic Backwash Filter

Cost Category	Total Filter Area (ft^2)				
	360	1,750	3,520	35,200	70,400
Excavation and Sitework	$ 290	$ 1,400	$ 2,630	$ 24,170	$ 47,300
Manufactured Equipment	103,380	185,650	361,760	3,262,210	6,513,820
Concrete	11,640	29,440	48,980	501,160	992,490
Steel	5,080	13,130	21,690	201,870	399,680
Labor	24,380	55,710	105,110	813,290	1,522,990
Piping and Valves	11,160	14,990	22,320	58,460	116,920
Electrical and Instrumentation	5,230	7,330	12,560	197,130	388,390
Housing	29,770	84,820	138,800	1,679,270	3,273,930
SUBTOTAL	190,930	392,470	713,850	6,737,560	13,255,520
Miscellaneous and Contingency	28,640	58,870	107,080	1,010,630	1,988,330
TOTAL	219,570	451,340	820,930	7,748,190	15,243,850

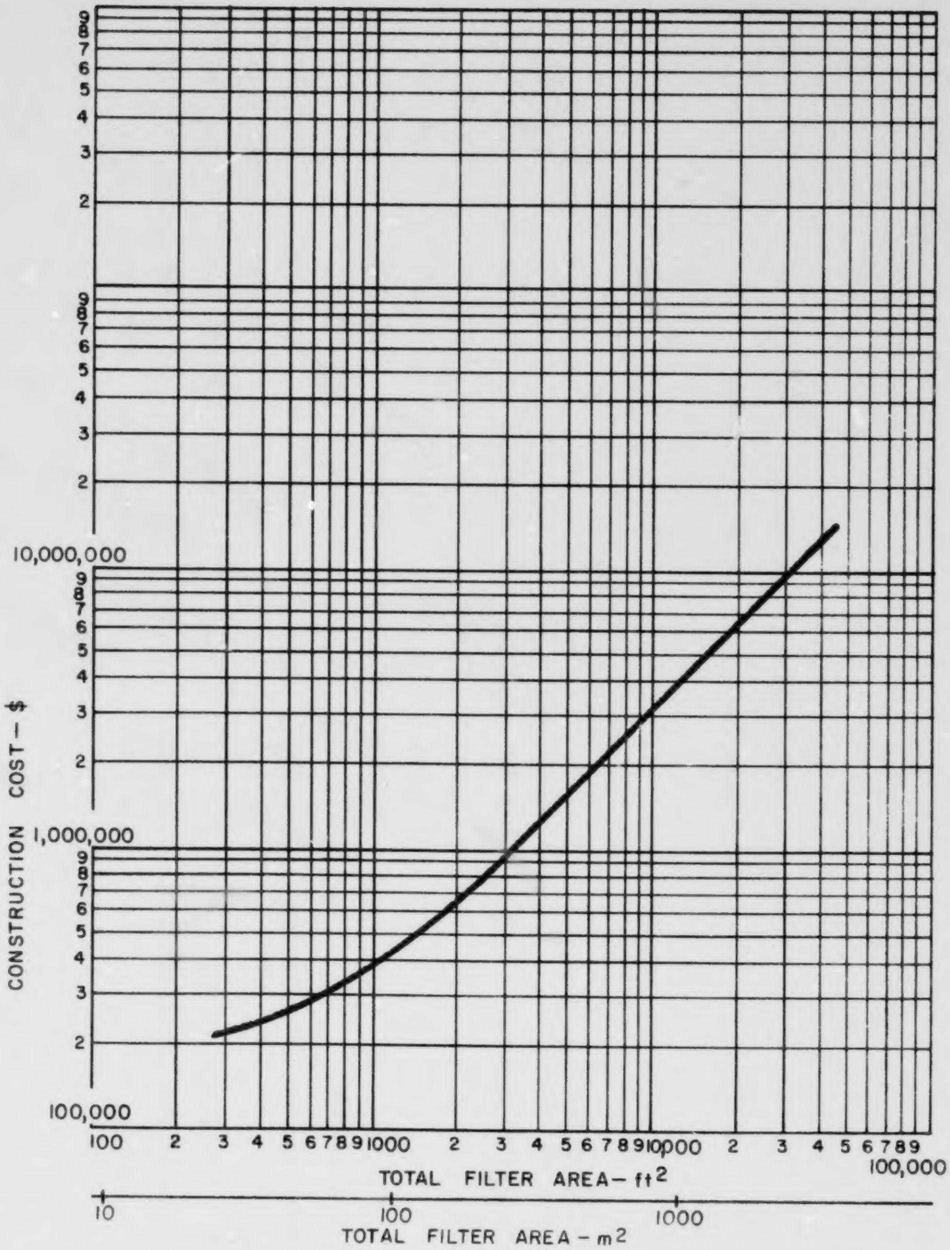


Figure 82. Construction cost for continuous automatic backwash filters.

Table 67

Operation and Maintenance Summary for Continuous Automatic Backwash Filter

Plant Flow (mgd)	Total Filter Area (ft^2)	Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1	360	111,629	3,854	115,483	$ 690	728	$ 11,430
5	1,750	341,863	13,624	355,487	1,500	832	20,480
10	3,520	627,912	42,890	670,802	2,350	1,040	32,870
100	35,200	8,372,160	428,900	8,801,060	20,310	10,000	384,340
200	70,400	16,685,325	857,800	17,543,125	37,420	18,000	743,710

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

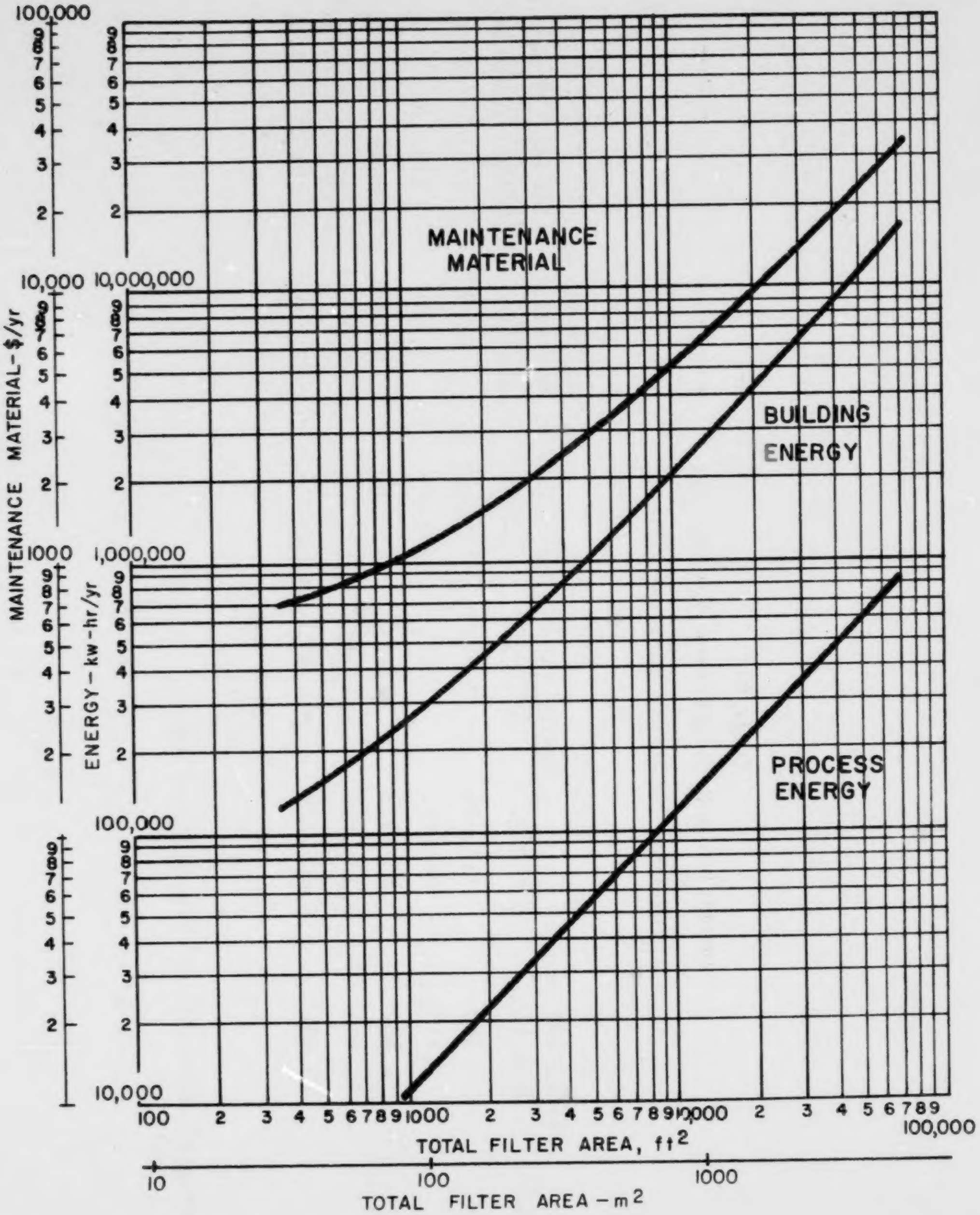


Figure 83. Operation and maintenance requirements for continuous automatic backwash filters - building energy, process energy, and maintenance material.

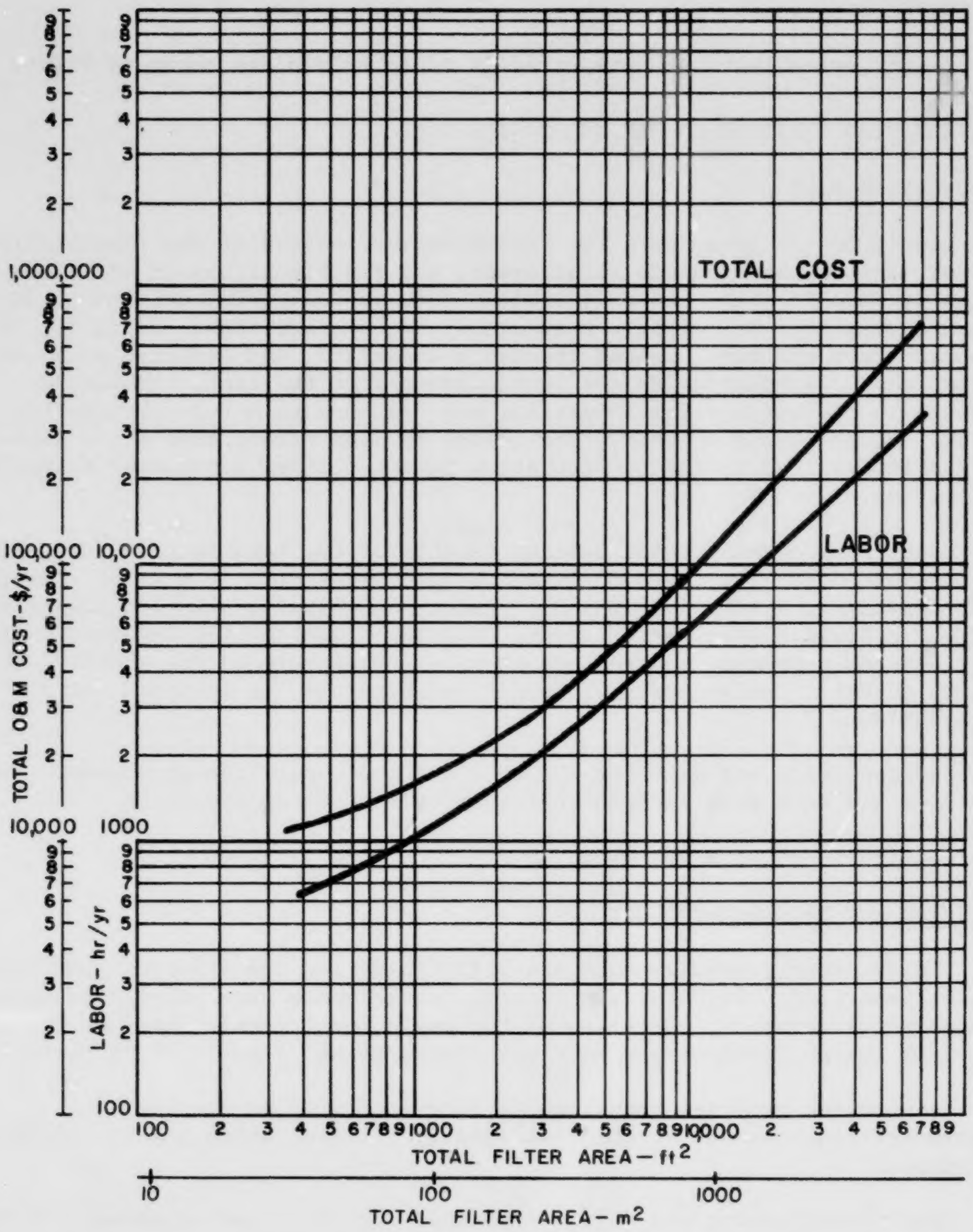


Figure 84. Operation and maintenance requirements for continuous automatic backwash filters - labor and total cost.

gas or liquid. Costs for the CO_2 piping and diffusers are included with the cost of CO_2 feed systems. Electrical costs are also included in the costs for CO_2 feed systems.

Construction costs are presented in Table 68 and are shown in Figure 85.

RECARBONATION - LIQUID CO_2 AS CO_2 SOURCE

Construction Cost

Liquid CO_2 is often used for recarbonation because of the flexibility of control, the low maintenance requirement, and the high transfer efficiency. Carbon dioxide is delivered to the plant site in bulk form, and stored in pressure vessels. To maintain pressure in the storage tank, liquid CO_2 is withdrawn from the tank, passed through a vaporizer, and returned as a gas to the tank. Carbon dioxide gas is withdrawn from the tank, reduced in pressure to prevent dry ice formation, and fed through a V-notch-type CO_2 feeder. Generally, a solution-type feeder is used rather than a gas feeder, since solution feed to the recarbonation basin provides a superior method of application.

Costs were developed for systems capable of CO_2 feed rates between 380 and 1,500 lb/day. The costs include a storage tank with 10 days of storage, a CO_2 vaporizer, a solution-type CO_2 feeder, an injector pump for the solution water, a stainless steel main header, diffuser pipes for the recarbonation basin, and an automatic control system using pH measurement for control to the CO_2 feeder. One standby CO_2 feeder and vaporizer is included for each installation.

Housing costs are only for the CO_2 feed and vaporizing equipment. No provision has been made for the enclosure of the CO_2 storage tank.

Construction costs are shown in Figure 86 and Table 69.

Operation and Maintenance Cost

Process energy requirements are principally for the injector pump and the CO_2 vaporizer. Injector pump energy requirements were calculated using a water requirement of 60 gal/lb of CO_2 and a total pumping head of 25 psi. Vaporizer energy requirements were calculated using 1 kw-hr/27 lb of CO_2 fed.

Maintenance material requirements were estimated on the basis of experienced requirements at chlorine feed facilities, which utilize similar equipment.

Labor requirements are only for periodic checking and adjustment of the feeder and vaporizer, since filling of the bulk CO_2 storage tank is performed by the tank truck driver.

Maintenance material requirements are summarized in Table 70 and presented in Figures 87 and 88.

Table 68
Construction Cost for Recarbonation Basin

Cost Category	Single Basin Volume (ft^3)						
	770	1,375	2,750	5,630	8,800	17,600	35,200
Excavation and Sitework	$ 520	$ 620	$ 980	$1,390	$1,790	$3,050	$5,570
Concrete	1,380	1,860	2,820	4,050	5,190	8,570	15,320
Steel	2,250	3,010	4,670	6,560	8,320	13,960	25,240
Labor	2,830	3,800	5,730	8,090	10,240	16,740	29,730
Pipe & Valves	90	130	250	480	680	1,360	3,360
SUBTOTAL	7,070	9,420	14,450	20,570	26,220	43,680	79,220
Miscellaneous & Contingency	1,060	1,410	2,170	3,090	3,930	6,550	11,880
TOTAL	8,130	10,830	16,620	23,660	30,150	50,230	91,100

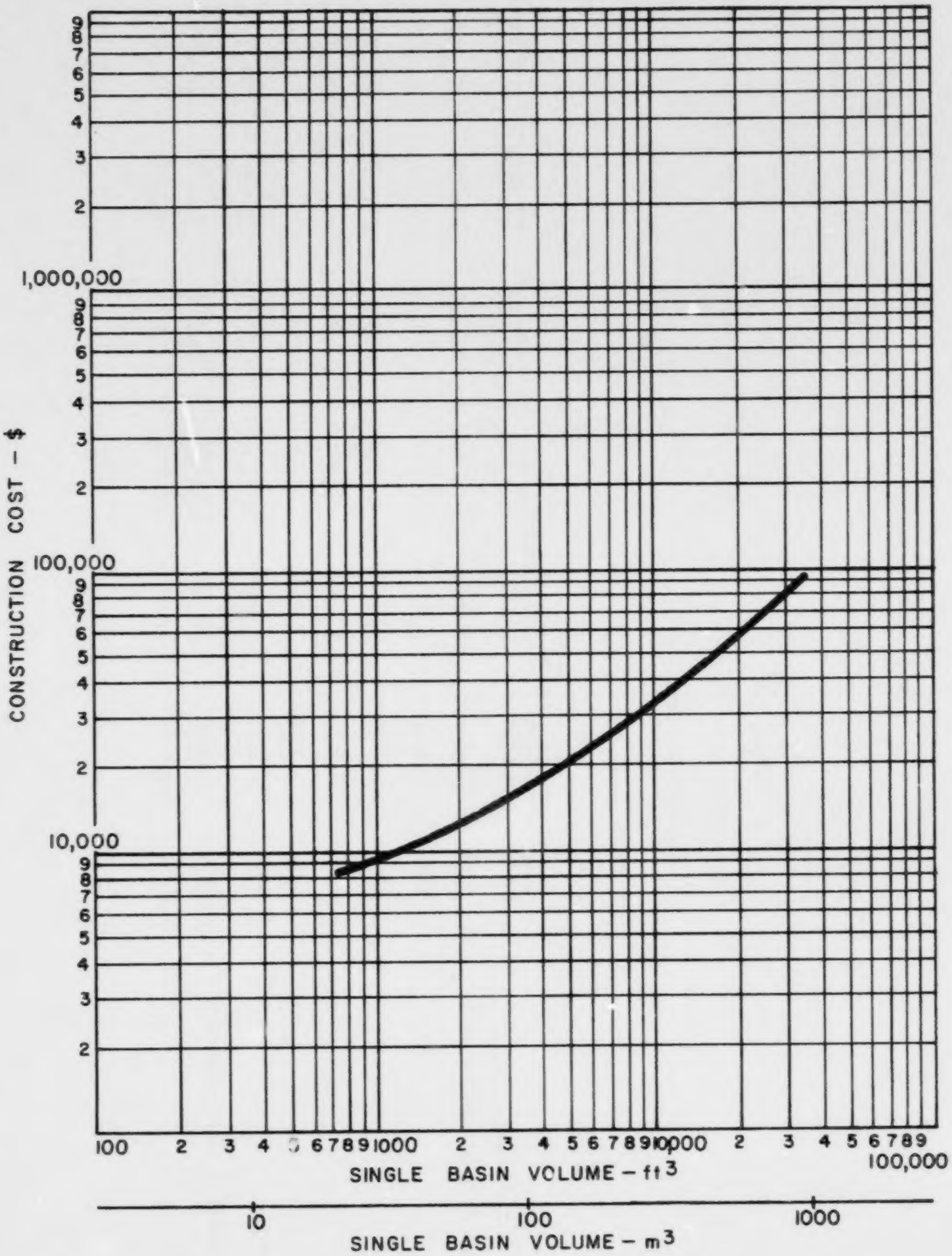


Figure 85. Construction cost for recarbonation basins.

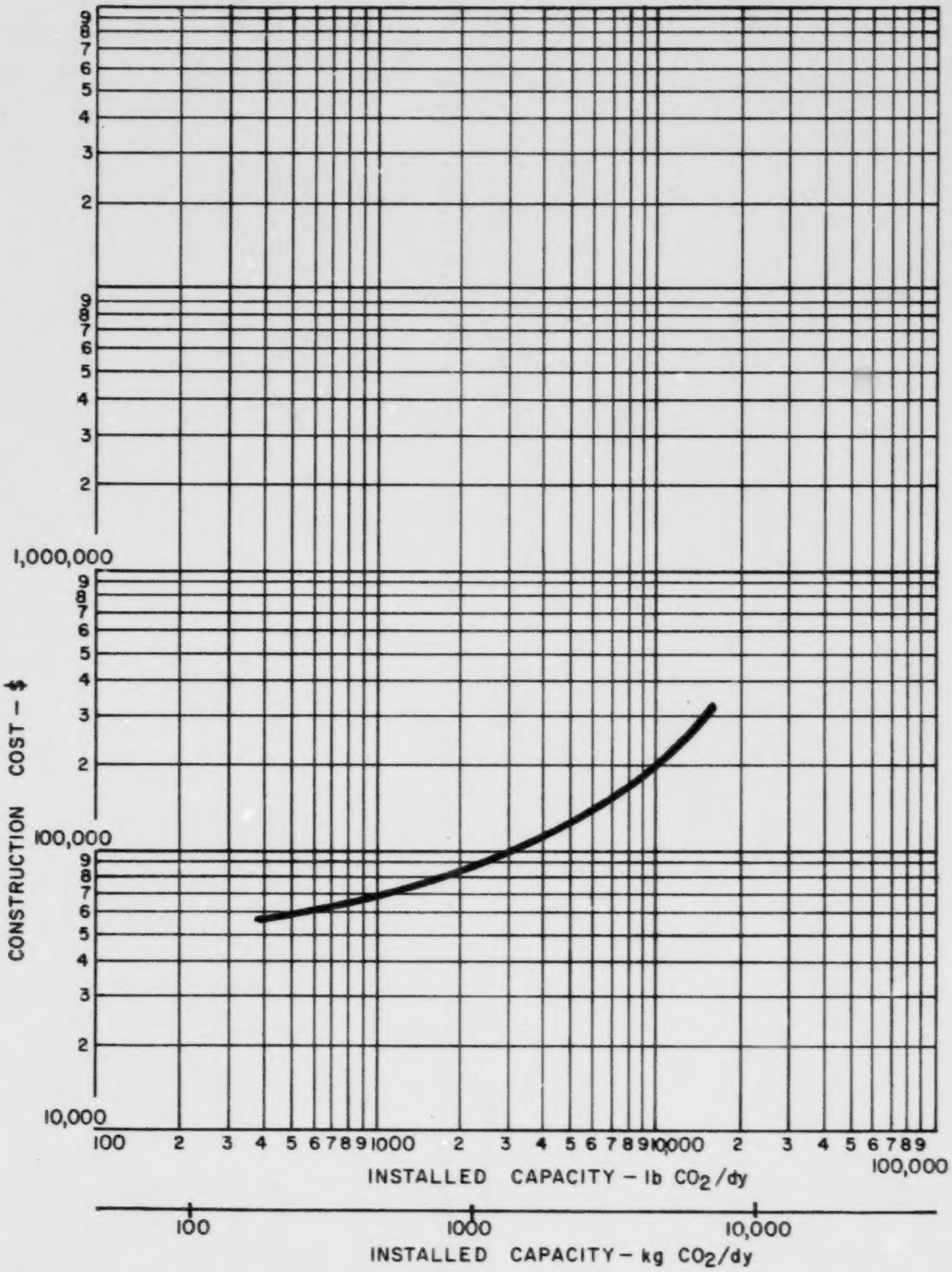


Figure 86. Construction cost for recarbonation - liquid CO_2 as CO_2 source.

Table 69

Construction Cost for
Recarbonation - Liquid CO_2 as CO_2 Source

Cost Category	Installed Capacity (lb/day) 380	750	1,500	3,750	7,500	15,000
Manufactured Equipment	$27,000	$ 31,000	$ 35,250	$ 49,250	$ 73,000	$ 141,000
Labor	7,650	8,780	12,170	17,330	28,990	58,010
Pipe and Valves	1,530	2,340	4,620	8,710	16,940	37,540
Housing	7,360	7,360	7,360	7,360	8,450	8,900
SUBTOTAL	43,540	49,480	59,400	82,650	127,380	245,450
Miscellaneous & Contingency	6,530	7,420	8,910	12,400	19,110	36,820
TOTAL	50,070	56,900	68,310	95,050	146,490	282,270

Table 70

Operation and Maintenance Summary for

Recarbonation - Liquid CO_2 as CO_2 Source

Installed Capacity (lb CO_2/day	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
380	10,260	7,070	17,330	$ 2,860	91	$ 4,290
750	10,260	14,020	24,280	3,300	91	4,940
1,500	10,260	27,970	38,230	4,400	91	6,460
3,750	10,260	66,080	76,340	5,500	182	9,610
7,500	15,390	132,220	147,610	7,700	182	13,950
15,000	20,520	264,450	284,970	10,000	273	21,280

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

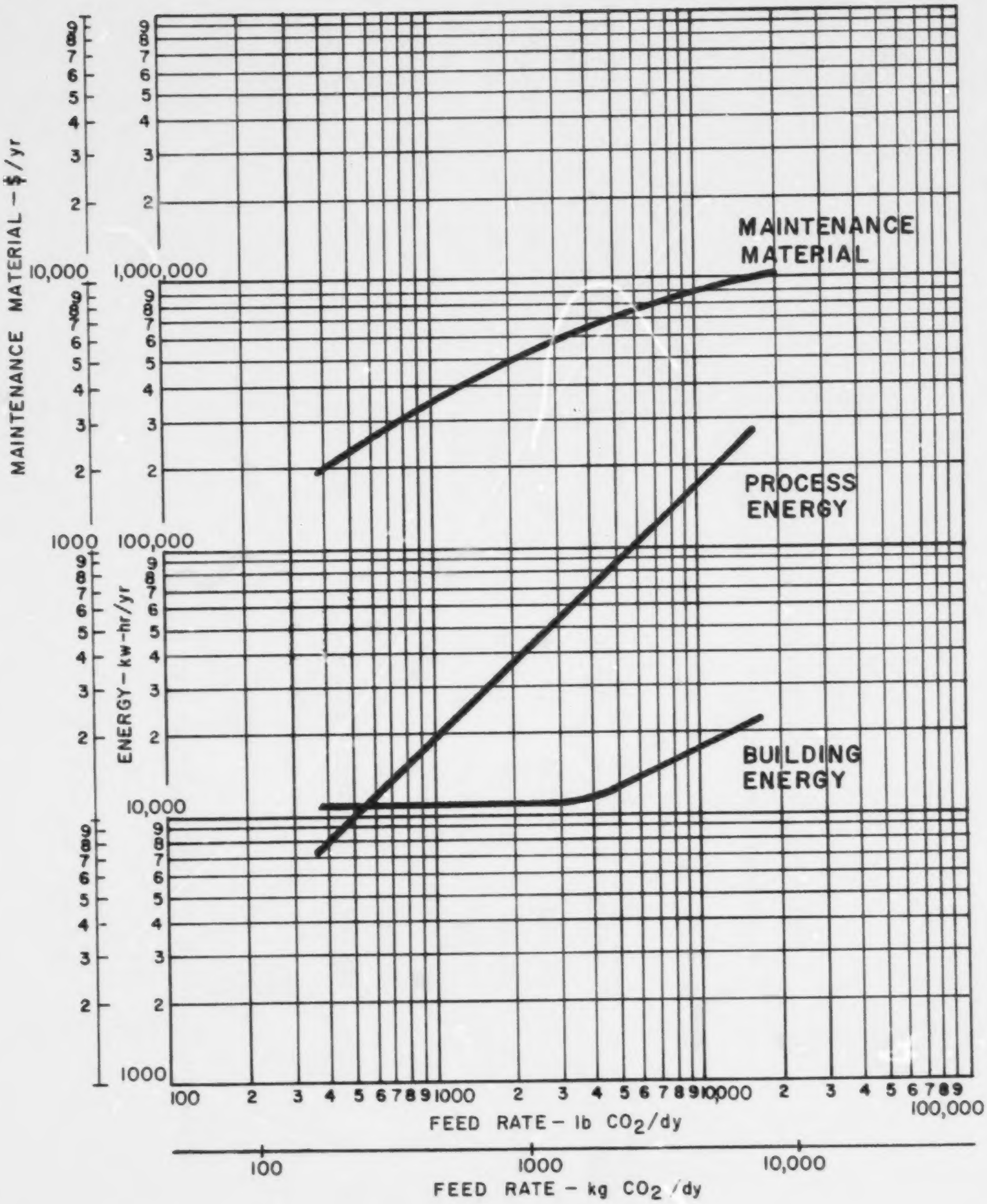


Figure 87. Operation and maintenance requirements for recarbonation - liquid CO_2 as CO_2 source - building energy, process energy, and maintenance material.

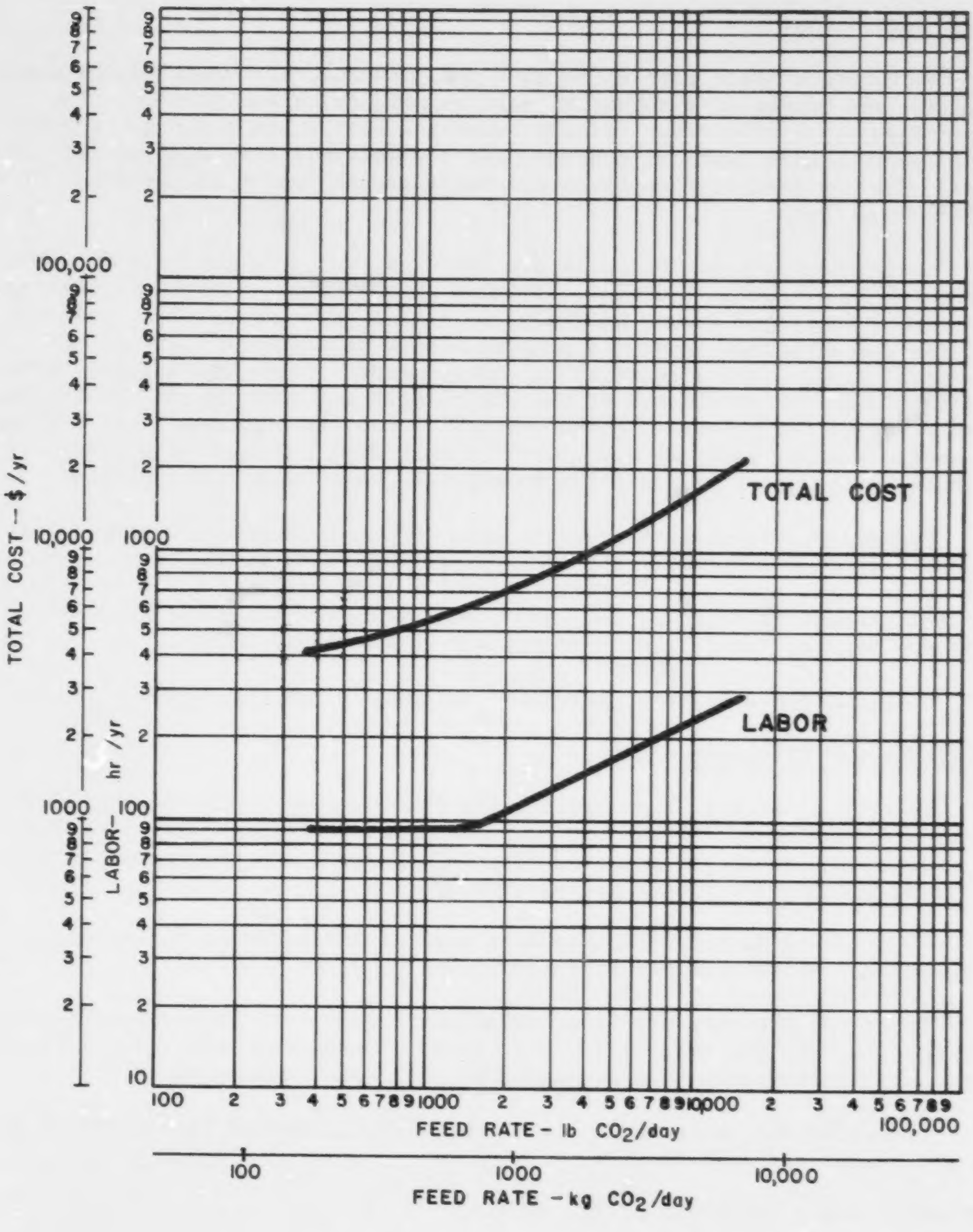


Figure 88. Operation and maintenance requirements for recarbonation - liquid CO_2 as CO_2 source - labor and total cost.

RECARBONATION - SUBMERGED BURNERS AS CO_2 SOURCE

Construction Cost

Sulfur-free fuels such as natural gas, propane, or butane may be combined with air and burned in a submerged unit to produce carbon dioxide. The advantages of recarbonation using a submerged burner are the high transfer efficiency, a high level of control, and a relatively low level of maintenance. The key disadvantage of this form of recarbonation is the need for a sulfur-free fuel.

Estimated construction costs are based on use of natural gas in submerged burners. Manufactured equipment included in the costs consists of the stainless steel submerged burner assembly, a centrifugal compressor to compress air for the submerged burner, a pump to supply impingement water to the submerged burner, and a centralized control panel. Pipe and valving costs are also included for conveyance of the air/natural gas mixture and the impingement water to the submerged burner assembly. Instrumentation costs are for automatic control using an electronic pH recording and control system. For systems using manual control, instrumentation costs should be deleted.

Generally, the largest capacity used for an individual submerged burner assembly is 10,000 lb/day. When greater rates are required, multiple burners are used. Also, since the burners generally have only a 2:1 delivery range, the requirement to vary CO_2 delivery over a greater range will require multiple burners rather than a single larger burner assembly.

Construction costs are presented in Table 71 and Figure 89.

Operation and Maintenance Cost

Process electrical requirements are for the pump supplying impingement water at 75 psig and for the air compressor delivering the air/natural gas mixture to the submerged burner at 9 psig. Natural gas requirements were based on manufacturers' recommendations.

Maintenance material requirements were estimated at approximately 5 percent/year of initial manufactured equipment costs.

Labor requirements are based on an oil change for the compressor every 100 hr, cleaning the air filter inlet once a month, and performing quarterly and annual maintenance as recommended by the burner manufacturer.

Operation and maintenance requirements are presented in Figures 90 and 91 and summarized in Table 72.

RECARBONATION - STACK GAS AS CO_2 SOURCE

Construction Cost

Water-sealed compressors are adequately suited to the compression of stack gases that have been passed through a wet scrubber. In sizing the

Table 71

Construction Cost for

Recarbonation - Submerged Burners as CO_2 Source

Cost Category	Installed Capacity (lb/day)					
	500	1,000	3,000	5,000	8,000	10,000
Manufactured Equipment	$27,800	$29,500	$35,100	$40,560	$49,660	$53,440
Labor	9,890	10,790	12,800	14,920	18,260	19,620
Pipe and Valves	5,000	5,880	10,650	10,650	14,400	14,400
Electrical & Instrumentation	3,950	3,950	4,600	5,050	5,050	5,050
SUBTOTAL	46,640	50,120	63,150	71,180	87,370	92,510
Miscellaneous & Contingency	7,000	7,520	9,470	10,680	13,110	13,880
TOTAL	53,640	57,640	72,620	81,860	100,480	106,390

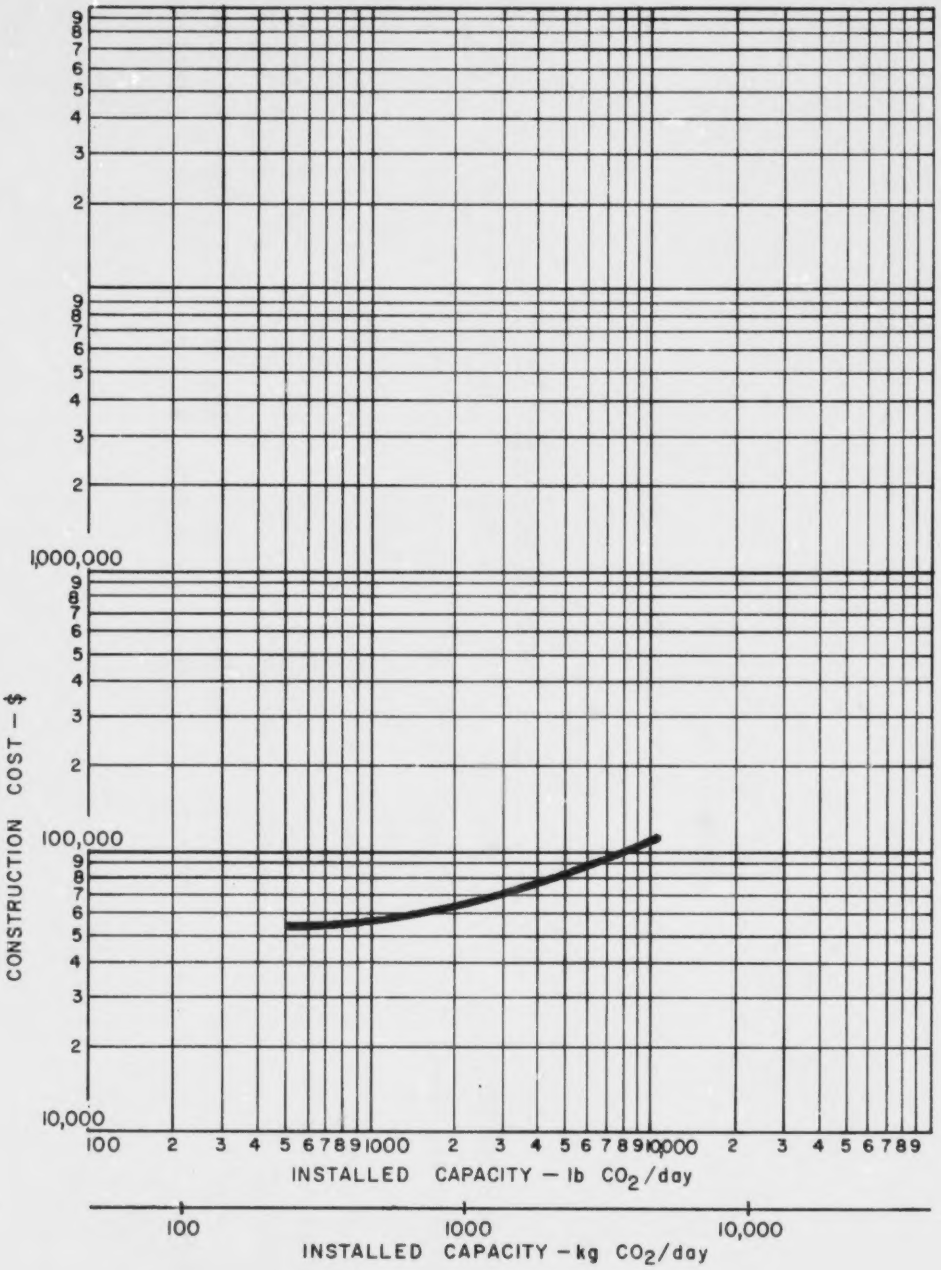


Figure 89. Construction cost for recarbonation - submerged burners as CO_2 source.

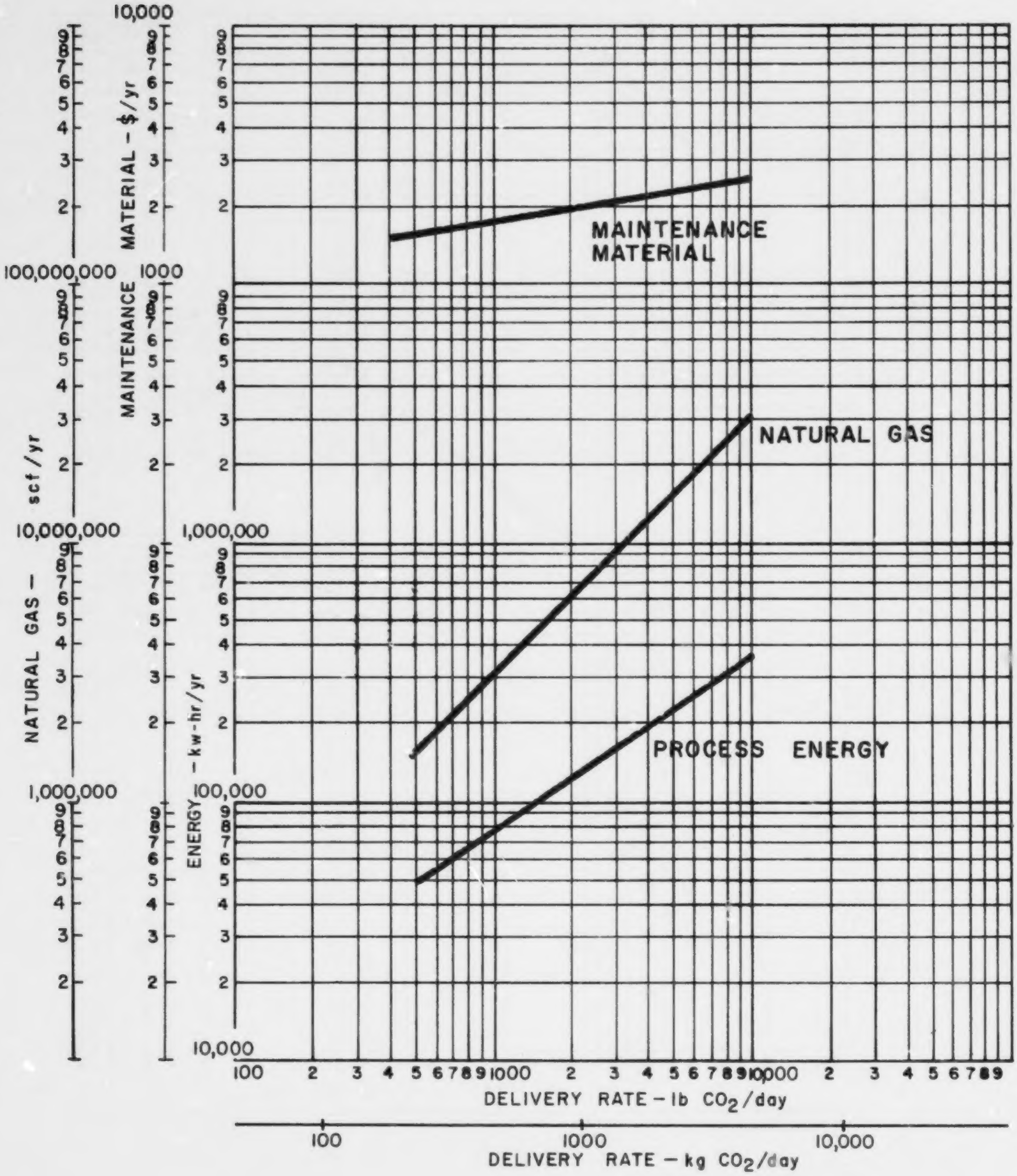


Figure 90. Operation and maintenance requirements for recarbonation - submerged burners as CO_2 source - natural gas, process energy, and maintenance material.

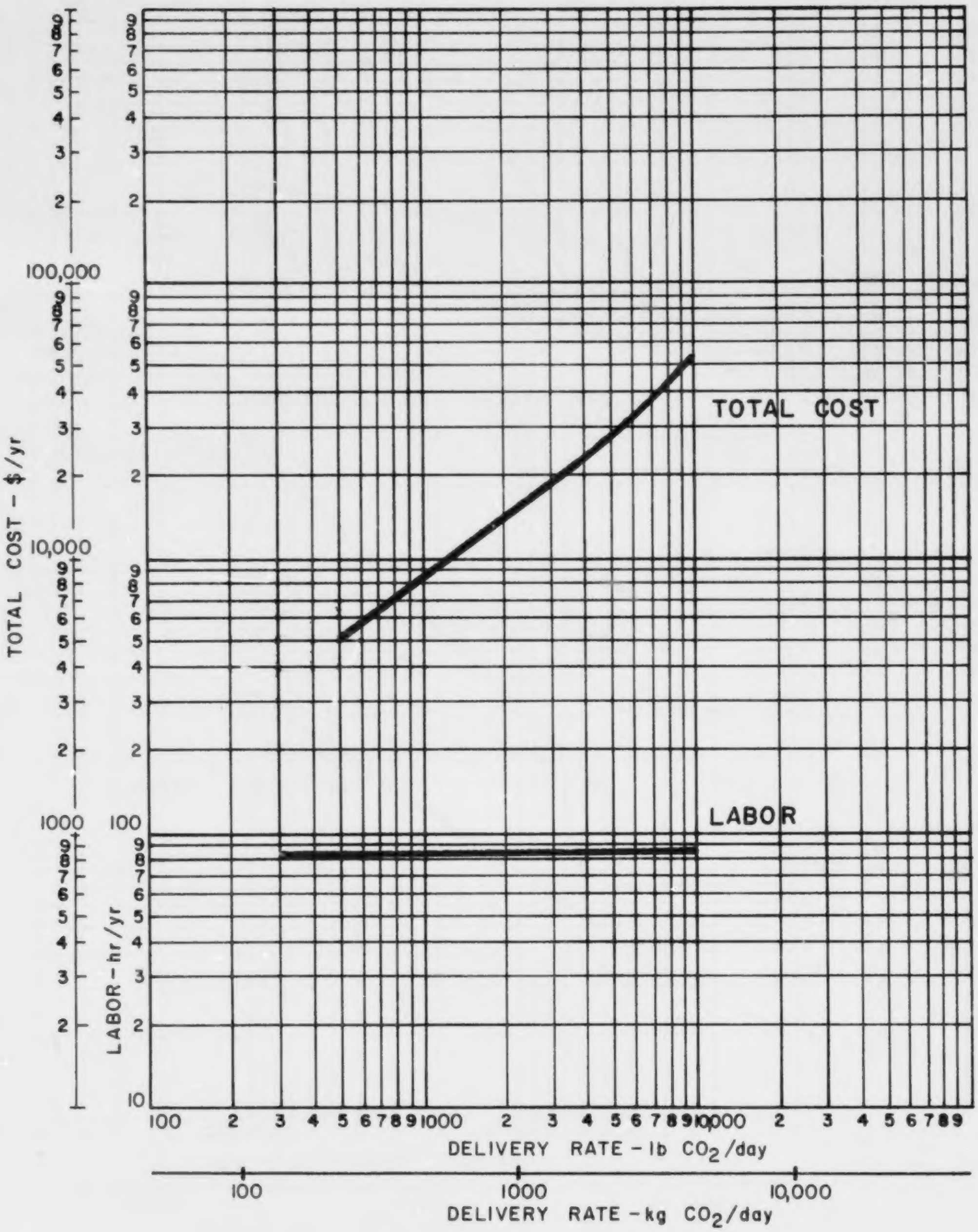


Figure 91. Operation and maintenance requirements for recarbonation - submerged burners as CO_2 source - labor and total cost.

Table 72

Operation and Maintenance Summary for Recarbonation - Submerged Burners as CO_2 Source

Installed Capacity ($lb\ CO_2/day$)	Process Energy (kw-hr/yr)	Natural Gas (scf/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
500	49,020	1,576,800	$1,540	80	$5,860
1,000	89,870	3,153,600	1,760	80	9,360
2,000	126,800	6,307,200	1,980	80	14,780
3,000	159,480	9,460,800	2,140	80	20,020
5,000	228,760	15,768,000	2,310	80	30,470
8,000	294,120	25,228,800	2,420	80	44,840
10,000	359,480	31,536,000	2,640	80	55,220

*Calculated using $0.03/kw-hr, $0.0013/scf of natural gas, and $10.00/hr of labor.

compressors, consideration should be given to multiple units to allow greater flexibility in rate of delivery. Flexibility can also be achieved by bleeding air into the stack gas before compression or by bleeding off a portion of the compressed CO_2. Such adjustments should be linked with a pH monitor.

Construction costs were developed for CO_2 compression systems that include the compressors, a compressed CO_2 supply line to the recarbonation basin, diffuser piping in the recarbonation basin, and a pH-controlled feed system.

Construction costs are summarized in Table 73 and presented in Figure 92.

Operation and Maintenance Cost

Process energy requirements were based on compression of the stack gas to 8 psi. Where greater pressures are required, appropriate adjustments should be made in the energy requirements.

Maintenance material costs are for compressor repair parts, valve maintenance, and maintenance of the electrical components. Labor requirements are for maintenance of the compressor and related accessories.

Operation and maintenance requirements are summarized in Table 74 and presented in Figures 93 and 94.

MULTIPLE HEARTH RECALCINATION

Construction Cost

Dewatered lime sludge, 30 to 60 percent solids, may be recalcined in a multiple hearth furnace. In the furnace, water and carbon dioxide are driven off from the lime sludge, leaving calcium oxide (quicklime), which may be slaked and reused. To avoid a buildup of inert solids in the system, it is necessary to waste a portion of the dewatered lime sludge or the recalcined lime.

Construction costs for lime-recalcining multiple hearth furnaces include the basic furnace and its associated screw conveyors, combustion air systems and cooling air fan, a stack gas scrubber, and controls. Conceptual designs for eight furnace configurations for which cost estimates were made are presented in Table 75.

Construction costs are presented in Table 76 and shown graphically in Figure 95.

Operation and Maintenance Cost

Process electrical energy costs include the center shaft drive, center shaft cooling fan, turboblower for burners, product cooler, and an induced draft fan. No allowance is included for carbon dioxide compressors, which are included with the stack gas recarbonation curves. Process energy consumption is not significantly affected by feed composition or moisture content. Building energy requirements are only for lighting and ventilation.

Table 73

Construction Cost for Recarbonation - Stack Gas as CO_2 Source

Cost Category	Capacity - (lb/CO_2/day*)			
	2,500	9,350	21,700	50,000
Manufactured Equipment	$18,280	$ 32,200	$ 38,490	$ 77,500
Labor	7,200	21,170	24,940	39,640
Pipe and Valves	1,500	10,400	14,080	21,280
Electrical & Instrumentation	3,000	10,500	17,000	20,500
SUBTOTAL	29,980	74,270	94,510	158,920
Miscellaneous & Contingency	4,500	11,140	14,180	23,840
TOTAL	34,480	85,410	108,690	182,760

*Based on a CO_2 concentration in the stack gas of 0.0116 lb CO_2/ft^3.

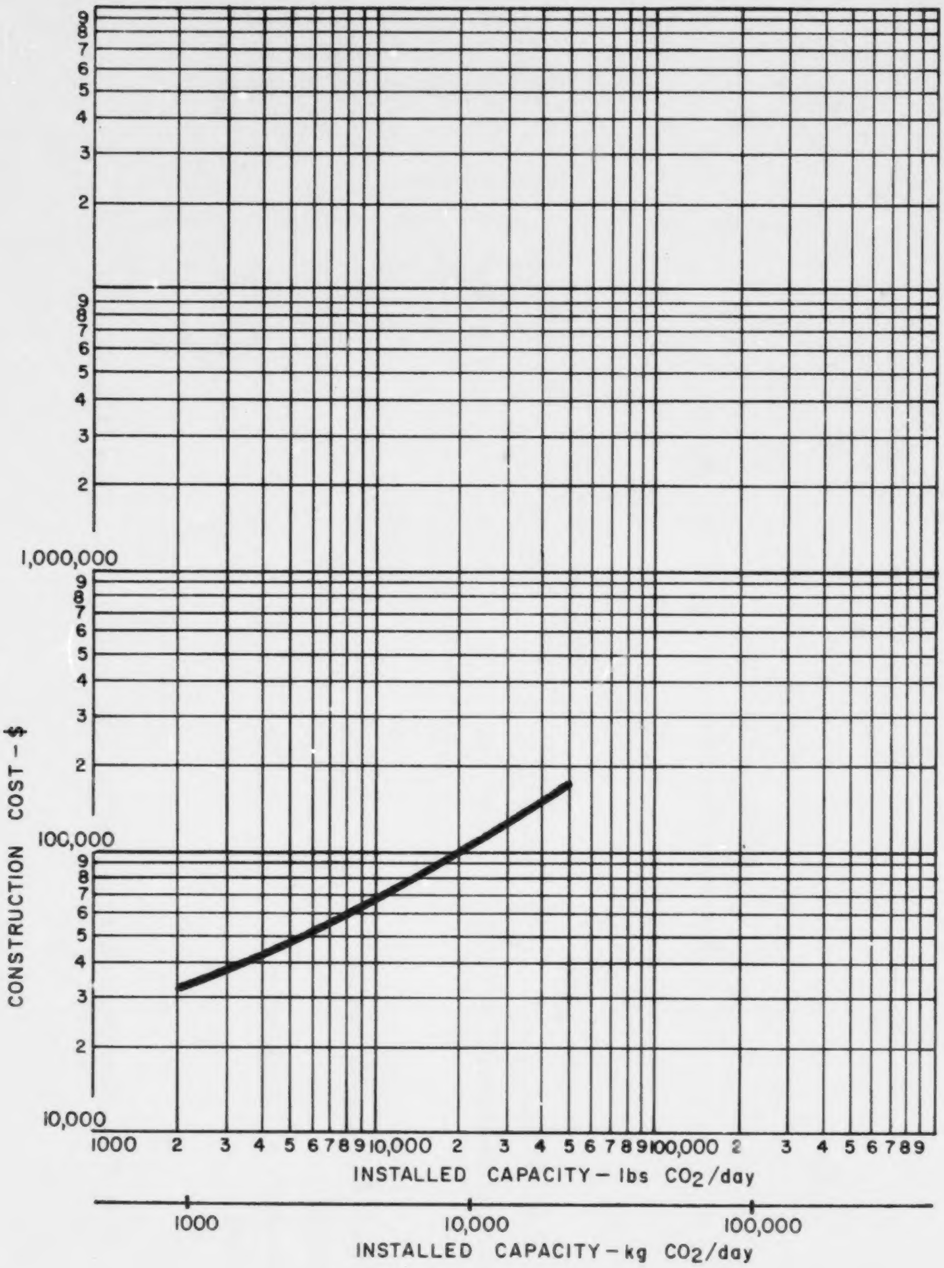


Figure 92. Construction cost for recarbonation - stack gas as CO_2 source.

Table 74

Operation and Maintenance Summary for Recarbonation - Stack Gas as CO_2 Source

Average Feed Rate (lb CO_2/day)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
2,500	43,260	$ 2,000	100	$ 4,300
9,350	161,670	3,600	250	10,950
21,700	375,370	5,200	440	20,860
50,000	866,210	7,900	750	41,390

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

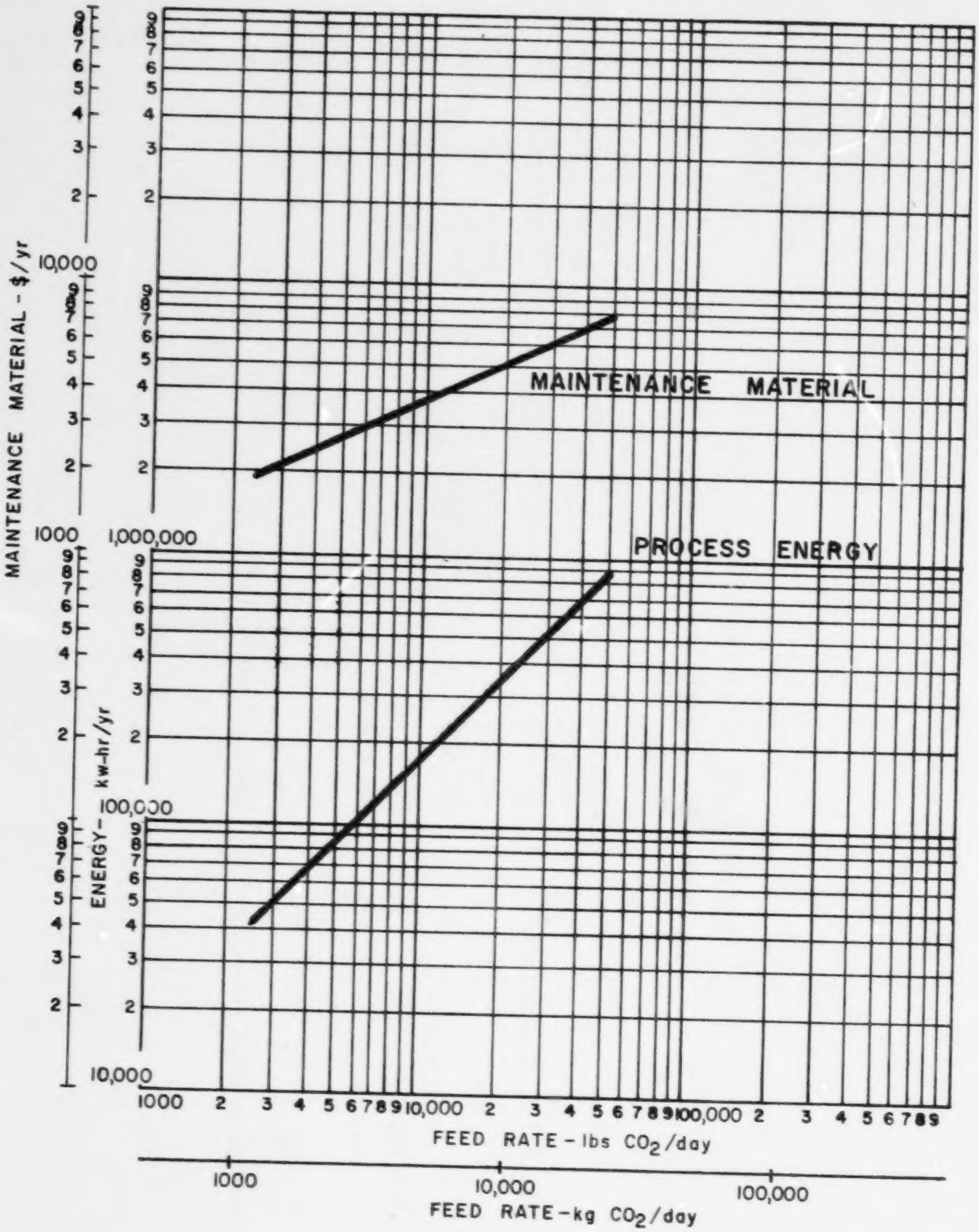


Figure 93. Operation and maintenance requirements for recarbonation - stack gas as CO_2 source - process energy and maintenance material.

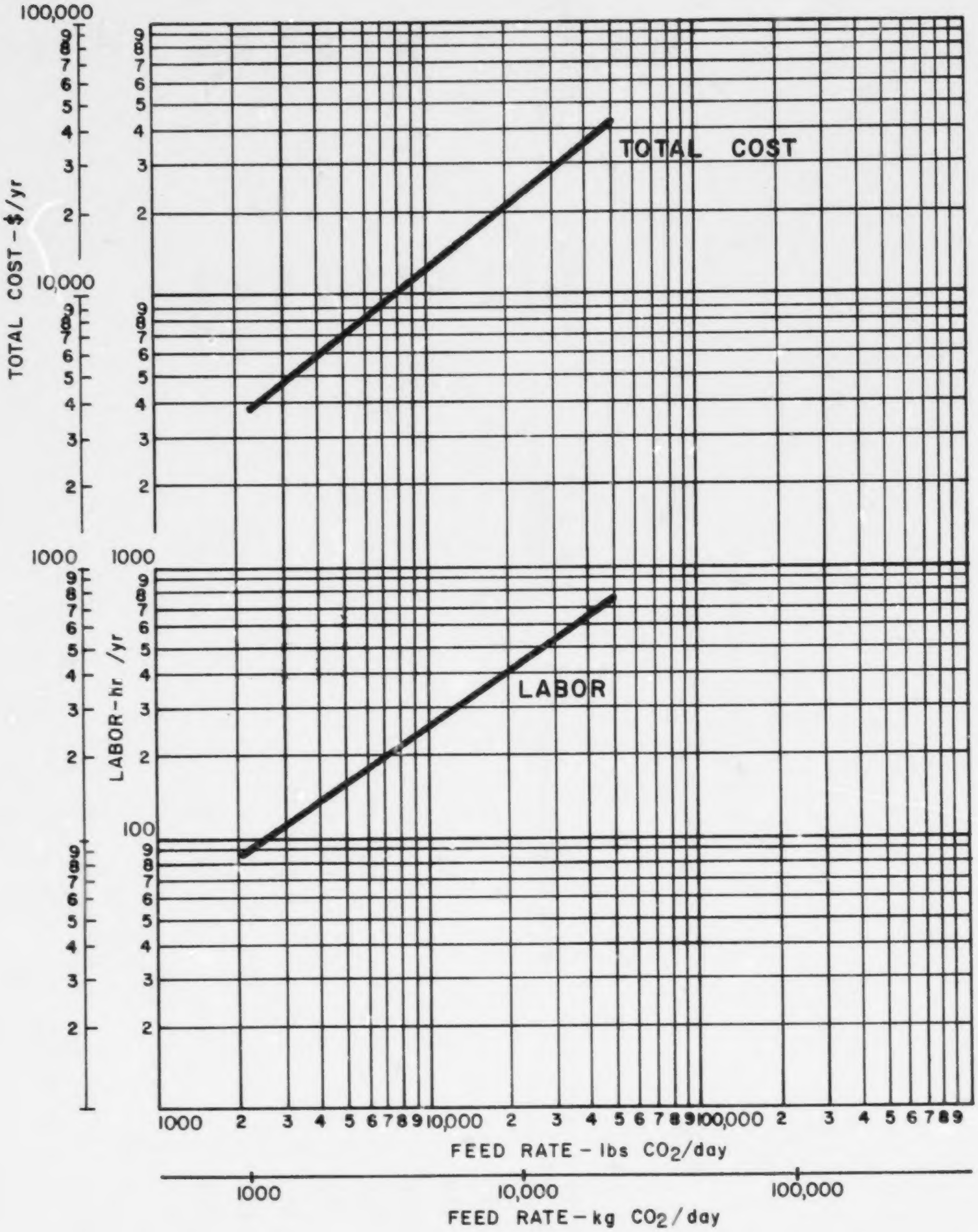


Figure 94. Operation and maintenance requirements for recarbonation - stack gas as CO_2 source - labor and total cost.

Table 75
Conceptual Design for
Multiple Hearth Recalcination

Effective Hearth Area (ft^2)	Furnace Diameter	Number of Hearths	Housing (ft^2)	Building Height (ft)
179	9' 3"	6	400	35
269	10' 9"	6	400	35
436	12' 10"	6	700	35
548	14' 3"	6	750	35
732	16' 9"	6	925	40
1,050	18' 9"	6	1,050	40
1,981	22' 3"	8	1,525	50
2,925	22' 3"	12	1,525	60

Table 76

Construction Cost for
Multiple Hearth Recalcination

Cost Category	Effective Hearth Area (ft^2) 179	269	436	548	732	1,050	1,981	2,925
Manufactured Equipment	$500,500	$539,000	$693,000	$847,000	$1,001,000	$1,155,000	$1,424,500	$1,694,000
Labor	214,500	231,000	297,000	363,000	429,000	495,000	610,500	726,000
Pipe & Valves	9,790	9,790	9,790	9,790	17,030	17,030	17,830	32,160
Electrical & Instrumentation	6,200	6,200	7,650	7,810	9,280	9,940	15,630	16,560
Housing	68,300	68,300	98,000	103,000	132,000	146,600	205,400	216,100
SUBTOTAL	799,290	854,290	1,105,440	1,330,600	1,588,310	1,823,570	2,273,860	2,684,820
Miscellaneous & Contingency	119,890	128,140	165,820	199,590	238,250	273,540	341,080	402,720
TOTAL	919,180	982,430	1,271,260	1,530,190	1,826,560	2,097,110	2,614,940	3,087,540

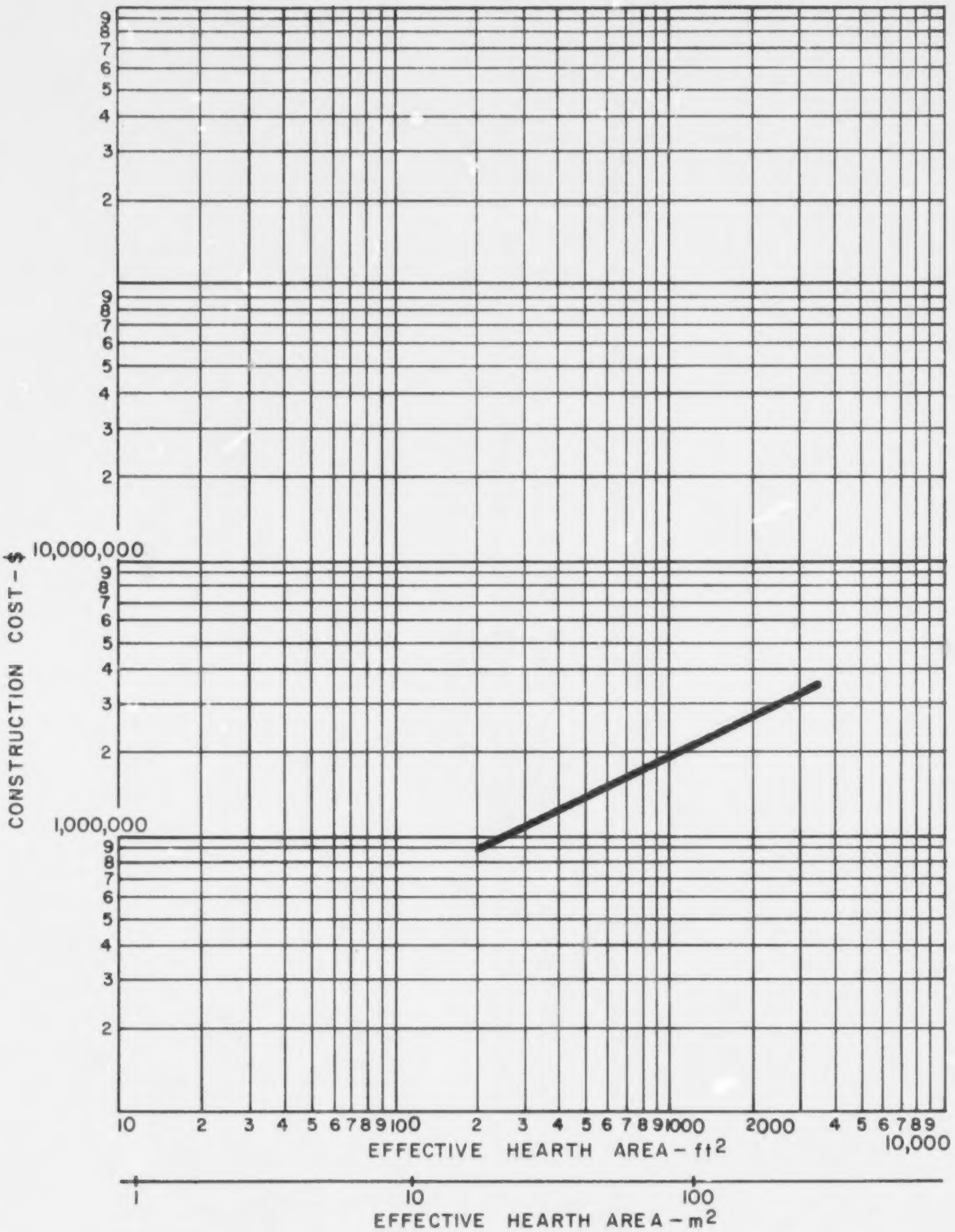


Figure 95. Construction cost for multiple hearth recalcination.

Natural gas requirements were calculated from manufacturers' recommendations using a dewatered sludge with a 45-percent solids content. Natural gas was considered to have a BTU content of 1,000/scf. When No. 2 fuel oil is utilized rather than natural gas, the number of gallons required can be calculated from the required BTU's of natural gas.

Maintenance material requirements are for routine repair of motor, drive assembly, and the refractory material. Labor requirements are principally for operation rather than maintenance and they are not significantly influenced by the sludge moisture content.

A summary of operation and maintenance requirements is presented in Table 77, and these requirements are also shown in Figures 96 and 97.

CONTACT BASINS

Construction Cost

A contact basin having a detention time of 1 hr is frequently used in direct filtration plants. The contact basin is normally located between rapid mix and filtration, and it is intended to even out surges in raw water turbidity and to serve as a sand trap. The contact basin allows plant operators to accommodate sudden turbidity variations, and it also provides chlorine contact time before filtration. The contact basin is not intended to remove flocculated turbidity and is not equipped with a sludge collector. Seasonal draining is normally sufficient to remove collected material.

Costs were developed for open, reinforced concrete contact basins. The conceptual designs for the basins were similar to rectangular clarifiers, with an 11-ft water depth. Costs are presented using single basin volume as the design parameter, although common wall construction was used in estimating costs. The construction costs are shown in Figure 98 and Table 78.

PRESSURE DIATOMITE FILTERS

Construction Cost

Diatomite filtration, also known as precoat or diatomaceous earth filtration, is applicable to direct treatment of surface waters or ground waters for removal of relatively low levels of suspended solids. In a pressure diatomite filter, the precoat material is applied to a supporting structure or septum within a pressure vessel, through which the water is passed under pressure for removal of suspended materials. When the pressure drop makes it impracticable to continue filtration, the filtering material is washed from the septum. In contrast to sand filtration, where the sand is washed and reused, the precoat filtering material is expended to waste, and a fresh coating is formed for each run. To prevent premature plugging of the precoat during a filter run, diatomaceous earth is fed continuously at a controlled rate with the water being treated.

Construction costs have been developed for a series of diatomaceous earth filter units capable of handling flows ranging from 1 to 200 mgd.

Table 77

Operation and Maintenance Summary for Multiple Hearth Recalcination

Effective Hearth Area (ft^2)	Electrical Energy (kw-hr/yr) Building	Process	Total	Natural Gas (scf/yr x 10^6)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
179	7,880	330,000	337,880	28	$ 6,100	3,000	$82,640
269	7,880	395,000	402,880	31.5	7,500	4,000	100,540
436	13,790	500,000	513,790	42	10,000	5,300	133,010
548	14,780	585,000	599,780	53	11,500	6,500	163,390
732	18,220	680,000	698,220	64	13,000	7,900	196,150
1,050	20,690	850,000	870,690	100	18,000	10,000	274,120
1,981	30,040	1,400,000	1,430,040	185	27,000	15,000	460,400
2,925	30,040	2,680,000	2,710,040	320	39,000	20,000	736,300

*Calculated on the basis of $0.03/kw-hr, $0.0013/ scf, and $10.00/hr of labor.

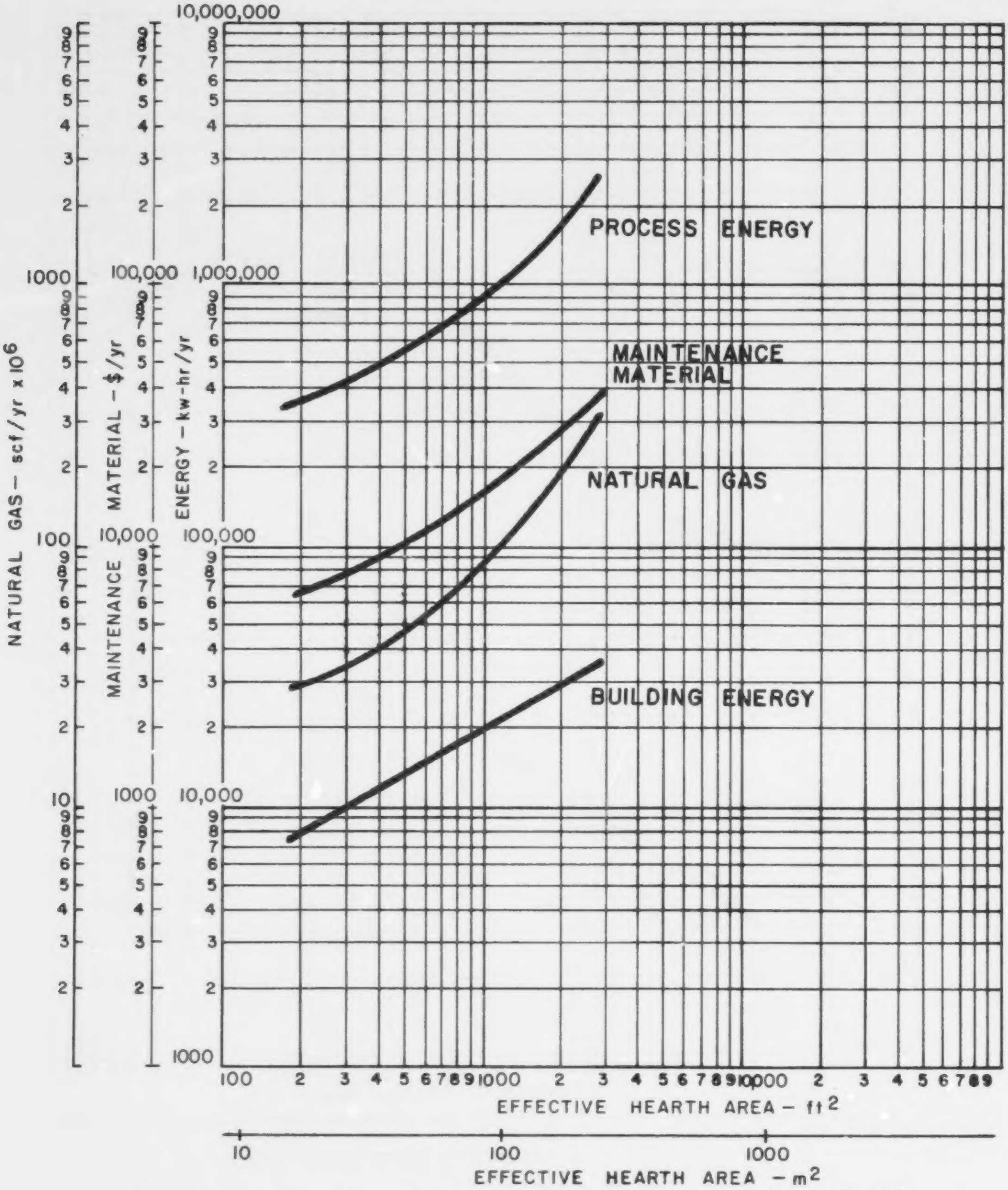


Figure 96. Operation and maintenance requirements for multiple hearth recalcination - natural gas, building energy, process energy, and maintenance material.

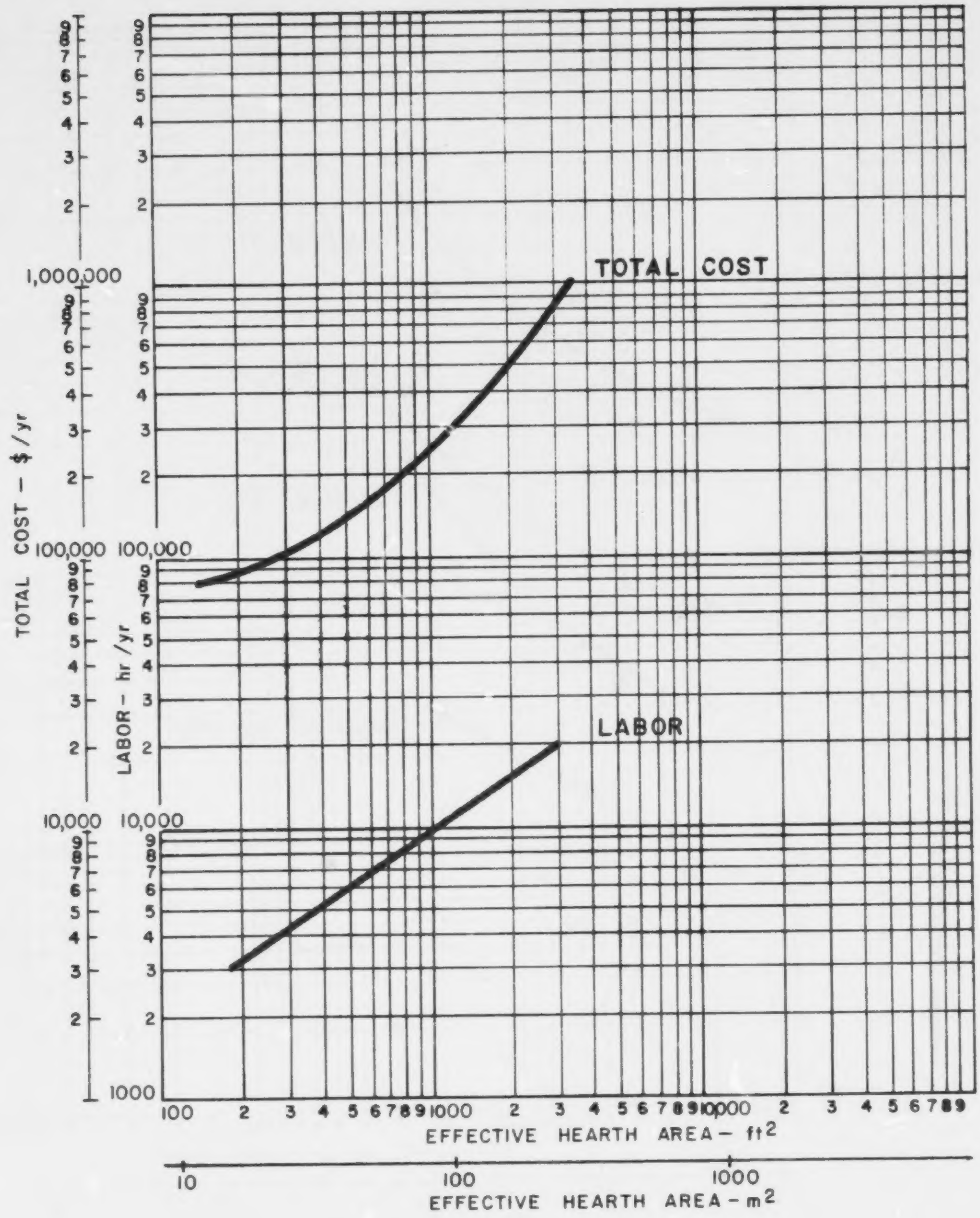


Figure 97. Operation and maintenance requirements for multiple hearth recalcination - labor and total cost.

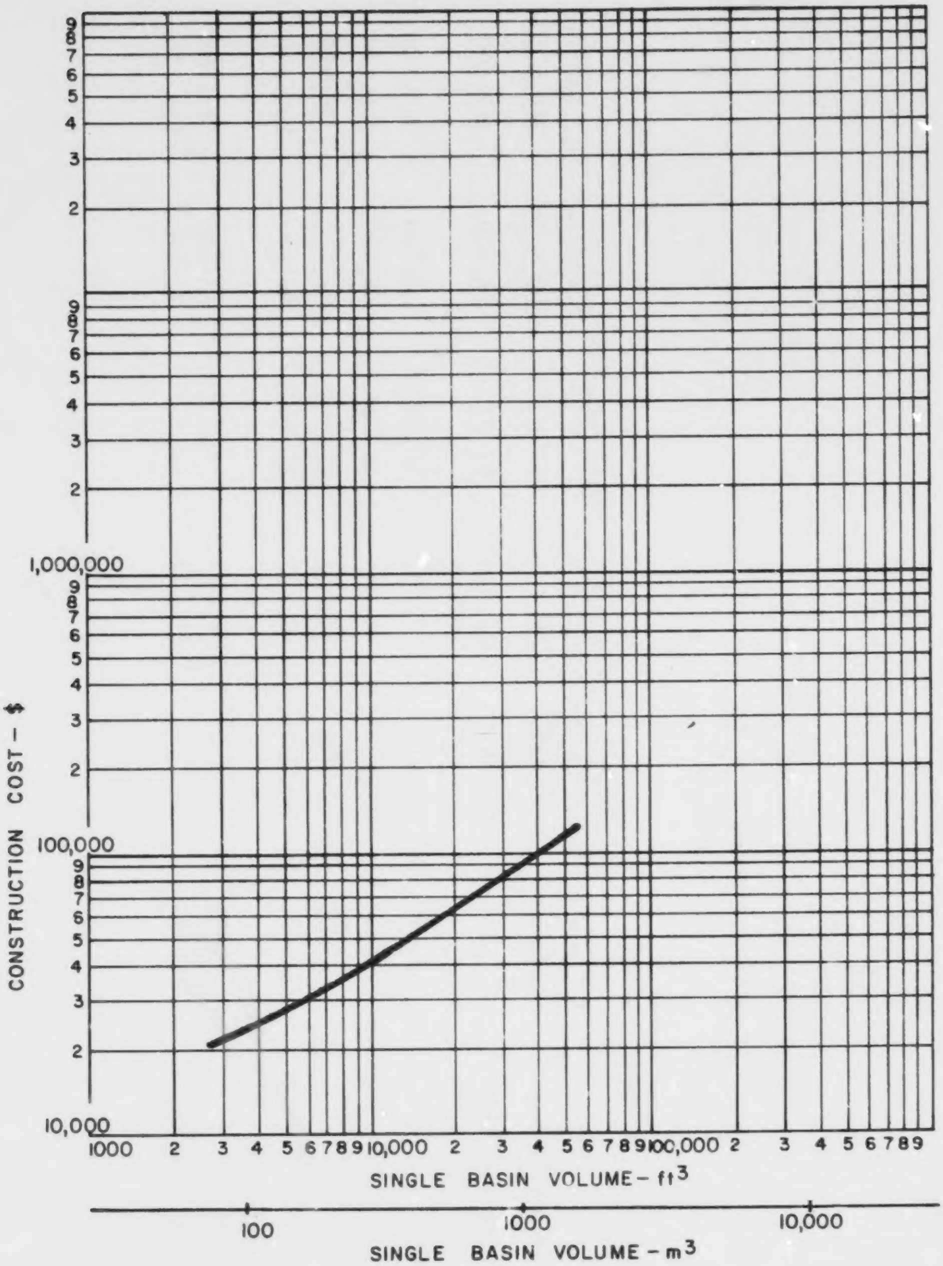


Figure 98. Construction cost for contact basins.

Table 78

Construction Cost for Contact Basins

Cost Category	Basin Volume (ft^3) and Length and Width (ft)					
	2,640 ft^3 30' x 8'	10,560 ft^3 80' x 12'	13,860 ft^3 100' x 16'	27,720 ft^3 140' x 18'	39,600 ft^3 200' x 18'	52,800 ft^3 240' x 20'
Excavation and Site-work	$ 1,250	$ 2,680	$ 3,510	$ 4,710	$ 6,320	$ 7,590
Concrete	3,490	7,370	9,690	12,950	17,230	20,710
Steel	5,900	12,440	16,130	21,480	28,680	34,270
Labor	6,960	14,390	18,640	24,660	32,700	38,970
SUBTOTAL	17,600	36,880	47,970	63,800	84,930	101,540
Miscellaneous & Contingency	2,640	5,530	7,200	9,570	12,740	15,230
TOTAL	20,240	42,410	55,170	73,370	97,670	116,770

The conceptual designs used to develop these construction costs are presented in Table 79. A filtration rate of approximately 1.6 gal/min per ft^2 of filter area, in accordance with manufacturers' recommendations, was used to size the filters. The cost estimates are for a complete installation, including diatomaceous earth storage, preparation and feed facilities, pressure filtration units, filter pumps and motors, filter valves, interconnecting pipe and fittings, and control panel for automatic operation. The costs also include complete housing of the filters. Excluded are costs associated with pretreatment, clearwell storage, and high-service pumping.

Construction costs are presented in Table 80 and also in Figure 99.

Operation and Maintenance Cost

Process energy usage is for filter pumps, backwash pumps, mixers, and other items associated with the filter system. A cycle time of 24 hr between backwashes was assumed in developing electrical requirements. The energy requirements do not include energy associated with raw water or finished water pumping.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, instruments and chemical feed pump replacement parts, and general facility maintenance supplies. Maintenance material cost estimates were furnished by manufacturers and are based on years of experience. Costs for treatment chemicals, including diatomaceous earth, are excluded. It should be noted that diatomaceous earth is a costly chemical, and its cost must be included.

Labor requirements were developed assuming that the diatomite filter installation operates automatically and virtually unattended. Operator attention is only necessary for preparation of body feed and precoat and for verification that chemical dosages are proper and that the equipment is producing a quality filtered water. No allowance was included for administrative or laboratory labor.

Operation and maintenance requirements are summarized in Table 81 and illustrated in Figures 100 and 101.

VACUUM DIATOMITE FILTERS

Construction Cost

Diatomite filtration, also known as diatomaceous earth or precoat filtration, can be used for removal of relatively low levels of suspended solids from surface or ground waters. In most surface water applications, pretreatment to remove the major amount of suspended material must be provided to allow satisfactory and economical operation. Ground waters containing low to moderate levels of oxidized iron and manganese can be treated successfully with diatomite filters.

The vacuum diatomite filter is composed of a multiplicity of flat, rectangular, filtering leaves arranged vertically at uniform spacing within

Table 79
Conceptual Design for
Pressure Diatomite Filters

Plant Flow (mgd)	Number of units	Tank Diameter (in.)	Filter Surface Area (ft^2)	Housing Requirements* (ft^2)
1	2	54	916	1,500
5	3	68	3,093	2,160
10	5	68	5,155	3,000
100	18	2-76	47,340	16,400
200	35	2-76	92,050	31,800

*Assumes that filter equipment is completely housed.

Table 80

Construction Cost for

Pressure Diatomite Filters

Cost Category	Plant Flow (mgd) 1	5	10	100	200
Excavation & Sitework	$ 500	$ 700	$ 1,000	$ 5,400	$ 11,000
Manufactured Equipment	155,000	330,000	525,000	4,200,000	8,000,000
Concrete	2,800	4,000	5,500	30,300	60,000
Steel	1,550	2,200	3,100	16,900	32,800
Labor	40,000	78,000	125,000	990,000	1,800,000
Pipe & Valve, Pumps	7,400	16,800	30,000	350,000	700,000
Electrical & Instrumentation	14,300	15,600	62,000	1,100,000	2,200,000
Housing	19,300	42,000	75,000	362,000	690,000
SUBTOTAL	240,850	489,300	826.600	7,054,600	13,493,800
Miscellaneous & Contingency	36,130	73,400	123,990	1,058,200	2,024,070
TOTAL	276,980	562,700	950,590	8,112,800	15,517,870

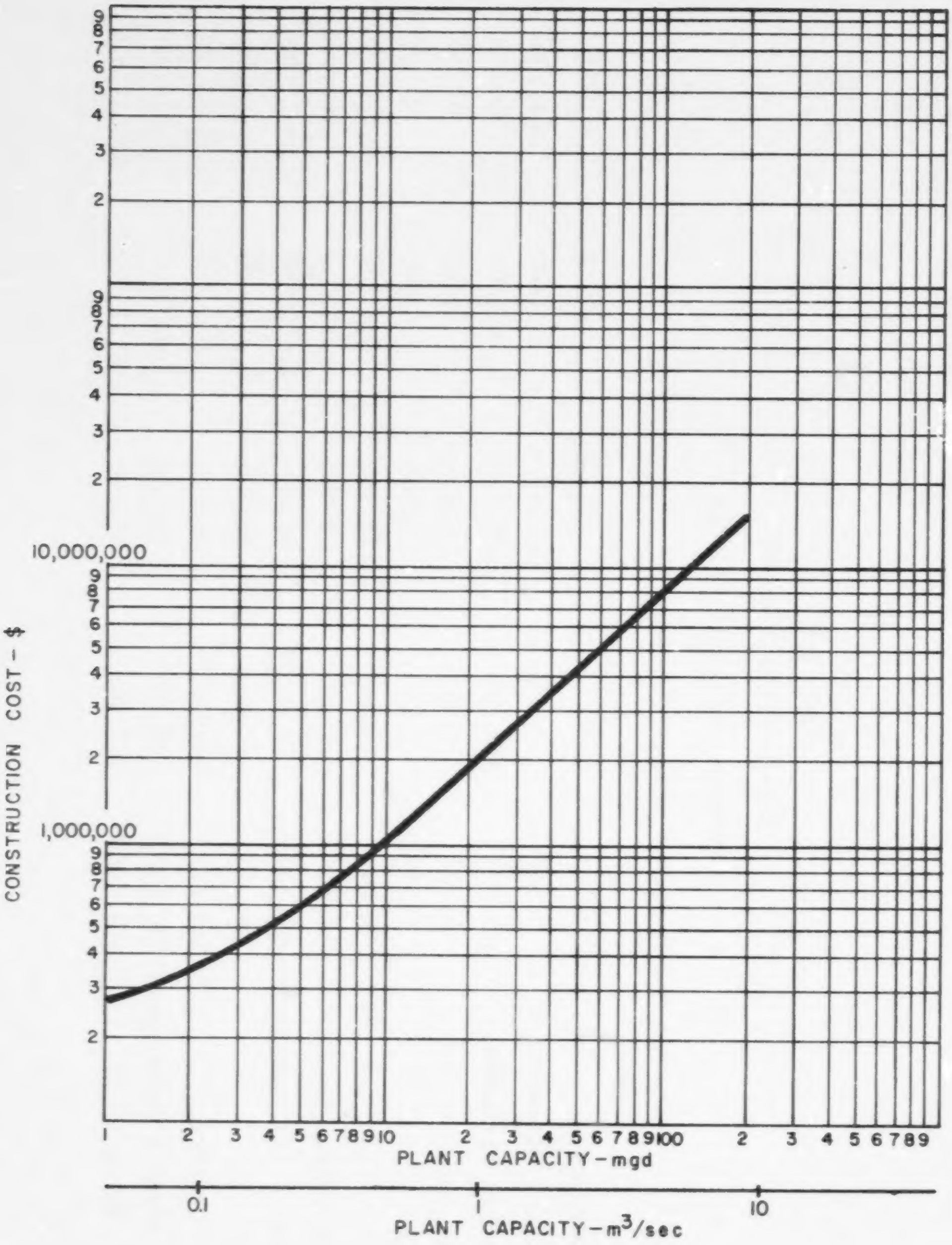


Figure 99. Construction cost for pressure diatomite filters.

Table 81

Operation and Maintenance Summary for Pressure Diatomite Filters

Plant Flow (mgd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
1	159,000	125,200	284,200	$ 1,500	2,920	$ 39,230
5	222,000	626,000	848,000	3,000	5,840	86,840
10	308,000	1,245,000	1,553,000	5,000	8,760	139,190
100	1,683,000	11,242,000	12,925,000	35,000	23,500	657,750
200	3,263,000	23,178,000	26,441,000	65,000	35,040	1,208,630

*Calculated using $0.03/kw-hr and $10.00/ hr of labor.

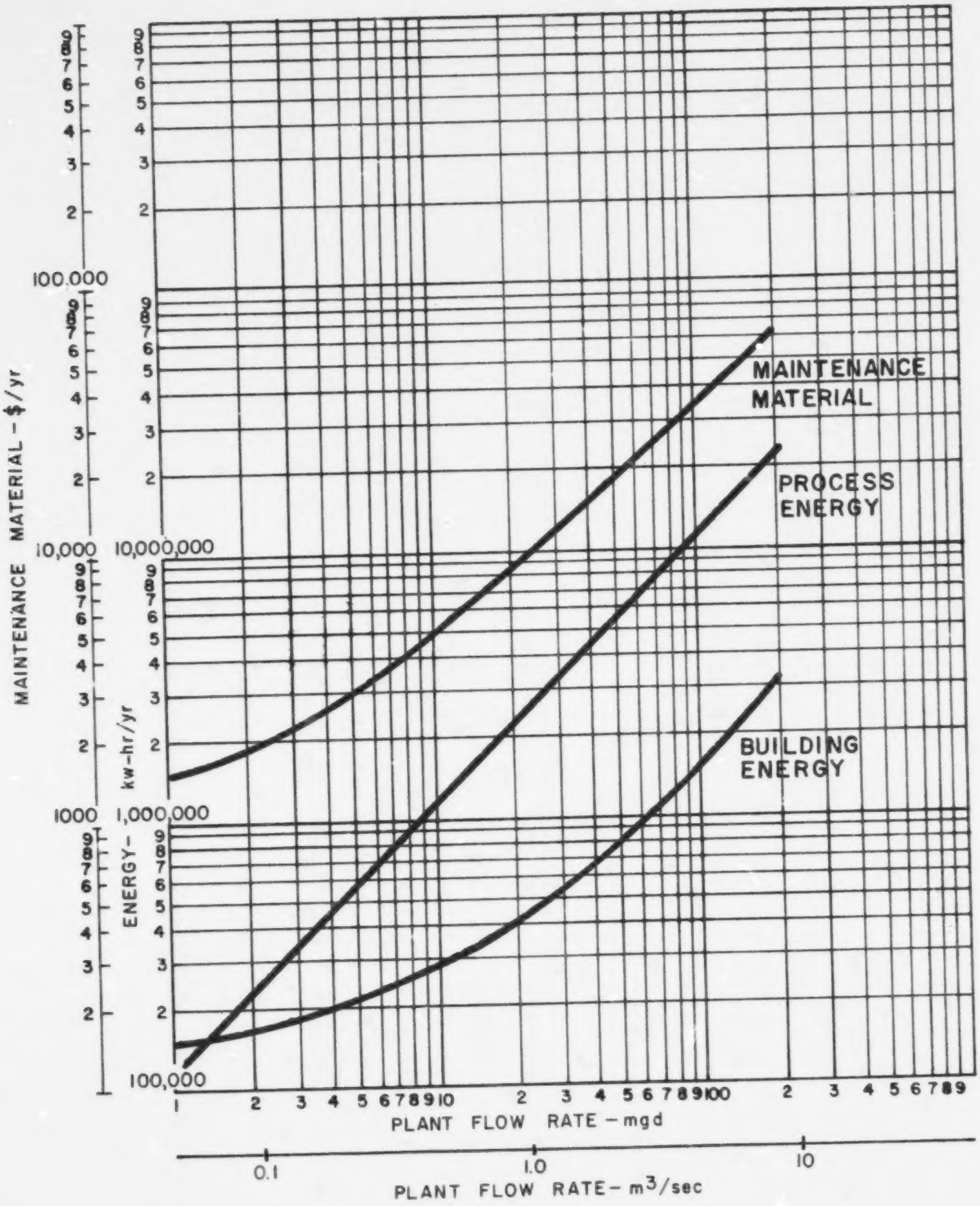


Figure 100. Operation and maintenance requirements for pressure diatomite filters - building energy, process energy, and maintenance material.

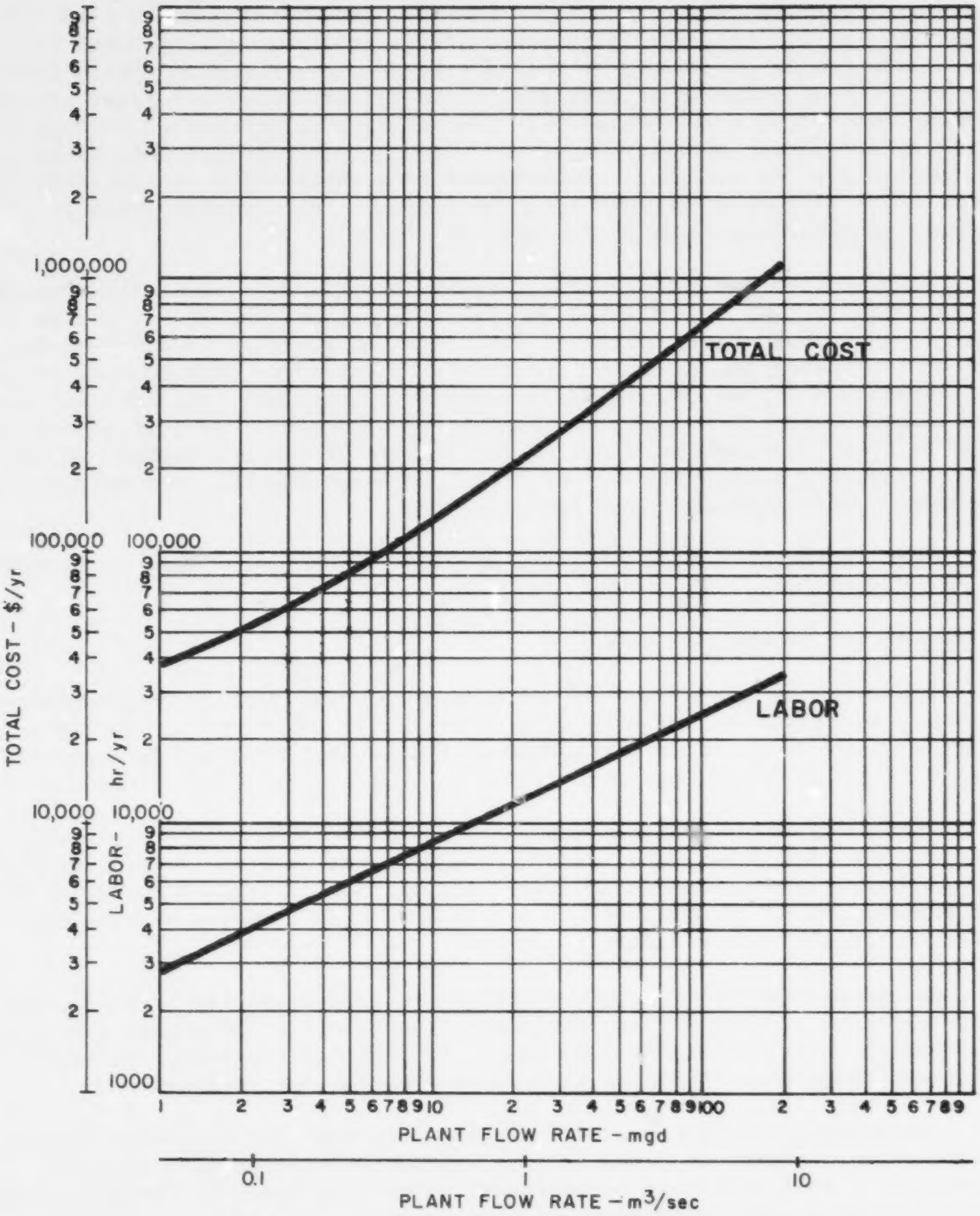


Figure 101. Operation and maintenance requirements for pressure diatomite filters - labor and total cost.

a shallow, open, baffled tank. Each unit is composed of a support structure, septum, and filtrate collector connected to a submerged suction manifold. Influent is introduced to each filter unit by gravity at a controlled rate. A filter pump applying suction to each filter leaf removes collected water and discharges it to storage or to distribution, depending on system design. During a normal operating cycle, the porous filter leaves are first precoated with a layer of diatomaceous earth. The porosity is maintained through the cycle by continuous application of body feed at a controlled rate along with influent. Cake discharge is accomplished by stopping flow and draining the tank, which dislodges the cake from the septum. The dislodged cake is carried to the plant sewer as the unit is drained.

Construction costs were for a complete installation, including diatomaceous earth storage, preparation and feed facilities, vacuum filtration units, filter pumps and motors, filter valves, interconnecting pipe and fittings, and control panel for automatic operation. These costs also include sitework and excavation within the immediate vicinity of the building, building pretreatment, clearwell storage, and high-service pumping. Conceptual designs used in these cost estimates are shown in Table 82. A filtration rate of approximately 1 gal/min per ft^2 of filter area was used to size filters, in accordance with manufacturers' recommendations.

Cost estimates for the vacuum diatomite filters are presented in Table 83 and Figure 102.

Operation and Maintenance Cost

Operating and maintenance requirements shown in Table 84 were developed for the conceptual designs presented in Table 82. The information used to develop these requirements was furnished by manufacturers and is representative of minimum operating requirements.

Process electrical energy usage is for filter pumps, backwash pumps, mixers, and other items associated with the filter system. A cycle time of 24 hr between backwashes was assumed in developing electrical requirements. The process energy requirements do not include those associated with raw water or finished water pumping.

Maintenance material requirements are related primarily to replacement of pump seals, application of lubricants, instrument and chemical feed pump replacement parts, and general facility maintenance supplies. Costs for treatment chemicals, including diatomaceous earth, are excluded.

Labor requirements were developed assuming that the diatomite filter installation operates automatically and virtually unattended. Operator attention is only necessary for preparation of body feed and precoat, chemical feed adjustment, and measurement of product water quality.

The operation and maintenance requirements summarized in Table 84 are illustrated in Figures 103 and 104.

Table 82
Conceptual Design for Vacuum Diatomite Filters

Plant Flow (mgd)	Total Filter Area (ft^2)*	Number of Units	Housing Requirements (ft^2)
1	720	1	740
5	3,060	3	3,500
10	6,120	6	5,600
100	61,200	60	54,000
200	122,400	120	108,000

*Based on a filtration rate of approximately 1 gal/min per ft^2 of filter surface area.

Table 83

Construction Cost for

Vacuum Diatomite Filters

Cost Category	Plant Flow (mgd) 1	5	10	100	200
Excavation & Sitework	$480	$1,040	$3,300	$ 27,000	$43,000
Manufactured Equipment	45,000	160,000	320,000	3,000,000	6,000,000
Concrete	550	2,700	4,000	35,000	65,000
Steel	540	1,500	3,000	28,000	56,000
Labor	30,000	110,000	200,000	1,800,000	4,000,000
Pipe and Valves	20,500	77,000	200,000	1,960,000	3,900,000
Electrical & Instrumentation	10,800	26,000	46,000	450,000	890,000
Housing	22,200	98,000	151,200	1,300,000	2,500,000
SUBTOTAL	130,070	476,240	927,500	8,600,000	17,454,000
Miscellaneous & Contingency	19,510	71,440	139,130	1,290,000	2,618,000
TOTAL COST	149,580	547,680	1,066,625	9,890,000	20,072,000

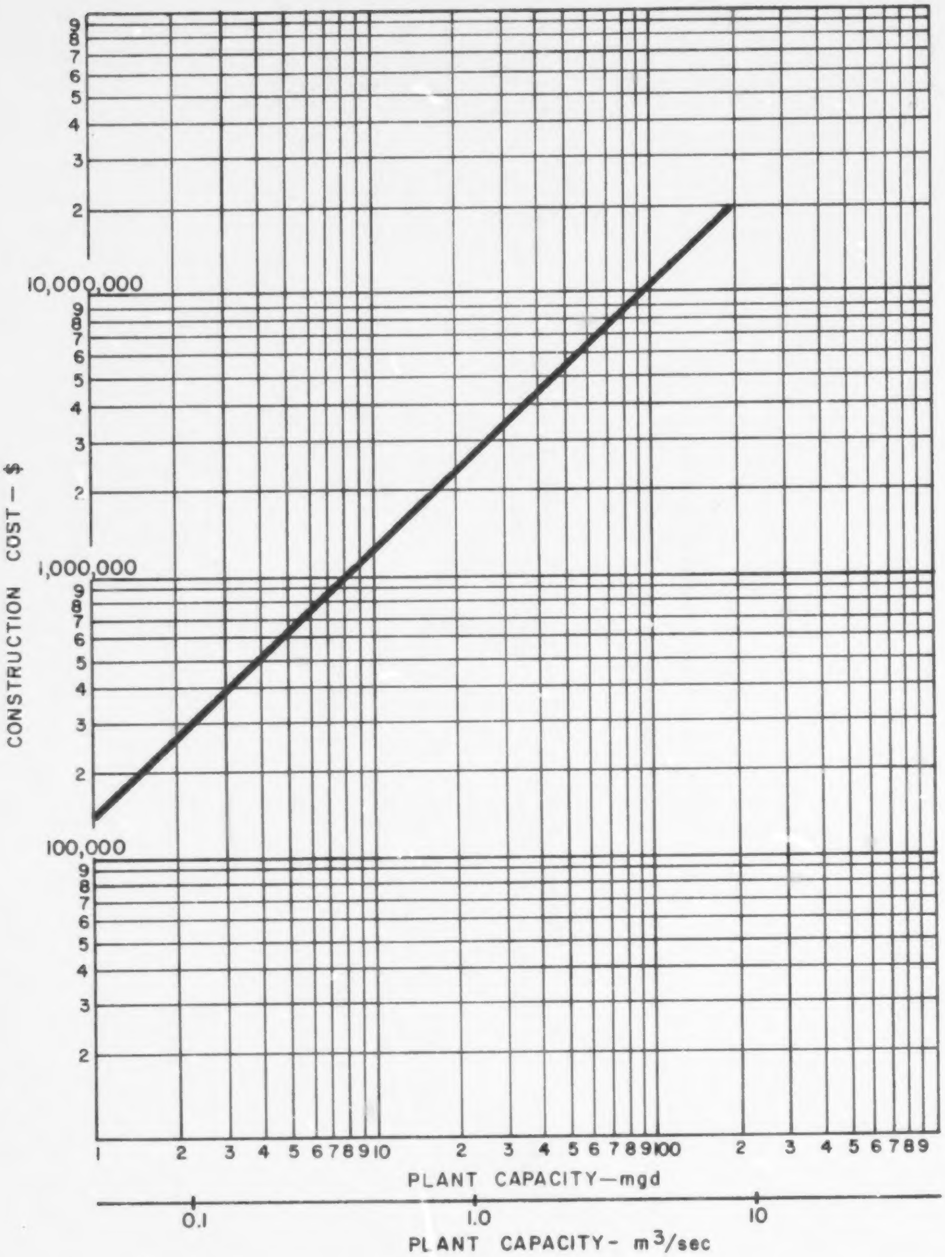


Figure 102. Construction cost for vacuum diatomite filters.

Table 84

Operation and Maintenance Summary for Vacuum Diatomite Filters

Plant Flow (mgd)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1	75,900	64,120	140,020	$ 750	2,900	$ 33,950
5	359,100	288,360	647,460	2,400	5,800	79,820
10	574,600	576,700	1,151,300	5,000	8,800	127,540
100	5,540,000	5,760,000	11,300,000	40,000	24,000	619,000
200	11,080,000	11,521,000	22,601,000	70,000	35,000	1,098,030

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

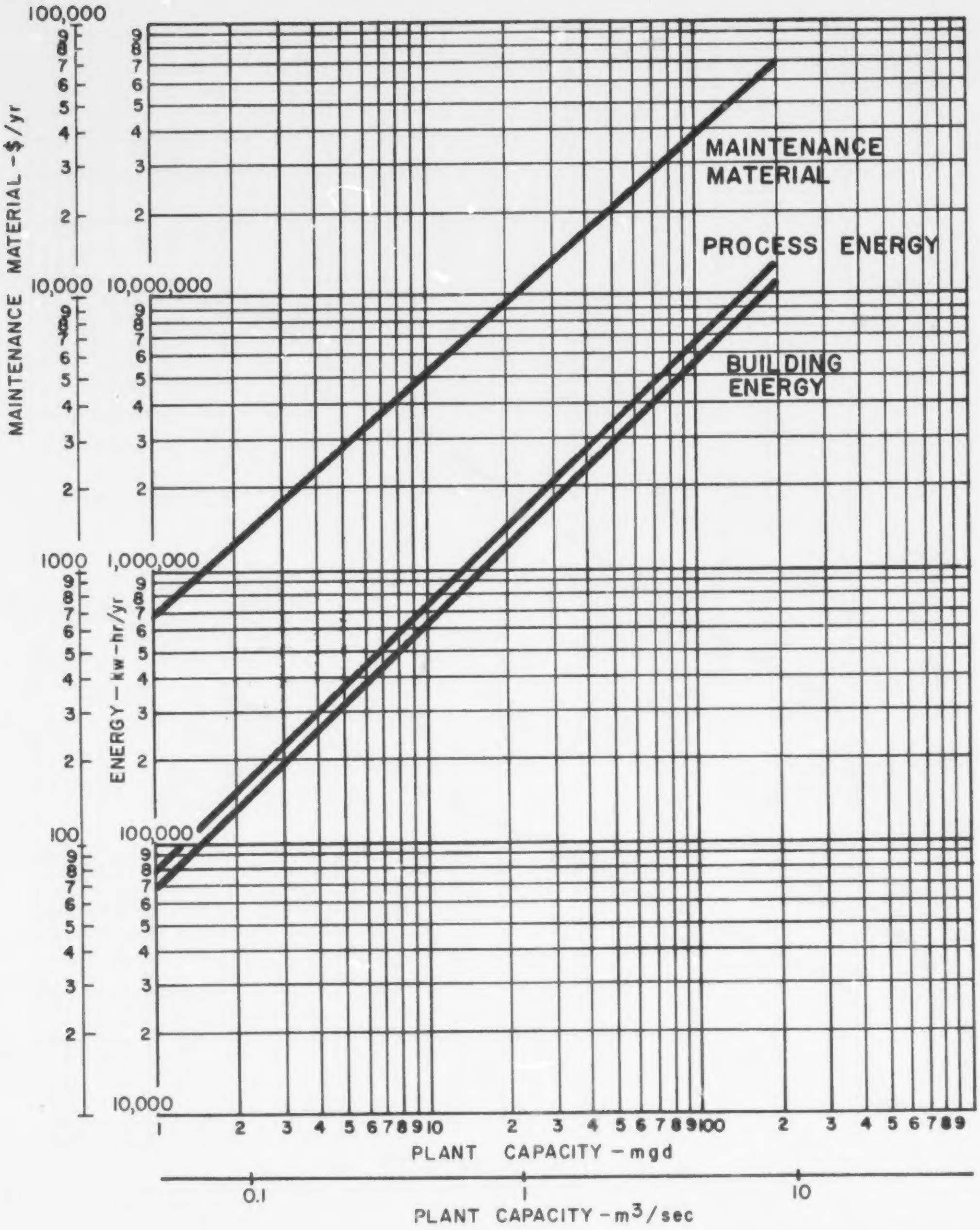


Figure 103. Operation and maintenance requirements for vacuum diatomite filters - building energy, process energy, and maintenance material.

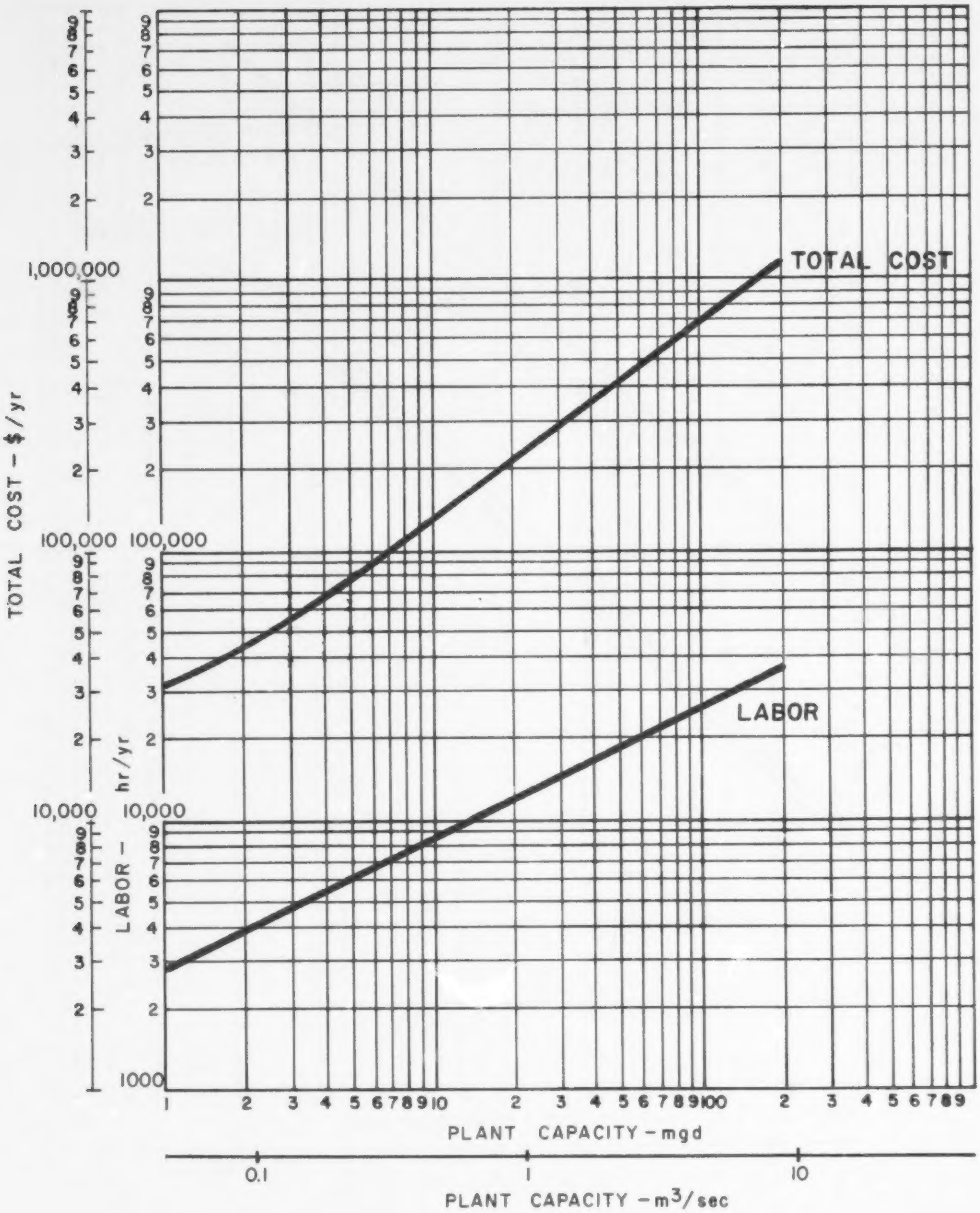


Figure 104. Operation and maintenance requirements for vacuum diatomite filters - labor and total cost.

PRESSURE FILTRATION PLANTS

Construction Cost

Costs have been developed for pressure filtration plants that are suitable for use with 24 to 36-in. deep filter beds consisting of rapid sand, dual media, or mixed media. Regardless of the media used, structural and hydraulic requirements of these media are similar. Filtration rates ranging between 2 and 7 to 8 gpm/ft^2 are possible, depending on the media utilized.

Cost estimates are based on use of either vertical or horizontal cylindrical ASME code pressure vessels of 50 to 75 psi working pressure. Each plant consists of a minimum of four vessels, with conceptual designs as shown in Table 85. Filter vessels are provided with a pipe lateral underdrain, and filter media are supported by graded gravel. This type of underdrain is suitable for water backwash with surface wash assist. For air-water backwashing, the pipe laterals are replaced with a nozzle underdrain.

Costs include a complete filtration plant with vessels, cylinder operated butterfly valves, filter face piping and headers within the filter gallery, filter flow control and measurement instrumentation, headloss instrumentation, and a master filter control panel. The filters are designed to backwash automatically on an input signal such as headloss, turbidity breakthrough, or elapsed time, or by manual activation. Not included in the cost estimate are supply piping to the filtration units from other unit processes, filter supply pumping, backwash storage and pumping, surface wash or airwash supply facilities, or filtration media. Housing requirements are based on the minimum rectangular space into which the facilities will fit. The basic housing includes covering of the pipe gallery (including a small portion of the ends of the tanks and a minimal service area for control panel) and other appurtenances related to the filtration structure (except for the 1 mgd plant, which because of its design and configuration is totally housed). The total housing requirement is for complete housing of the filters and pipe gallery, which would only be necessary in the most severe climates.

Estimated construction costs, including only basic housing, are shown in Figure 105 and in Table 86.

Operation and Maintenance Cost

Energy requirements were developed from the conceptual designs for process and for heating, lighting, and ventilating the basic housing requirement. Process energy is for the filtration system supply pumps and backwash pumps. Continuous 24 hr/day, 376 day/year operation with one backwash per day of 10 min duration was assumed. It was further assumed that the surface wash supply would be obtained from the pressurized distribution system with suitable means for backflow prevention.

Maintenance material costs are for additional filter media, charts and ink for recorders, and miscellaneous repair items for electrical control equipment and valves.

Table 85

Conceptual Design for Pressure Filtration Plants

Plant Flow (mgd)	Total Filter Area (ft^2)*	Filter Vessels			Plant Area Requirements, (ft^2)+	Housing (ft^2)	
		Number	Diameter and Length (ft)	Area Each (ft^2)		Basic	Total‡
1	140	4	**	35	2,100	2,100	2,100
10	1,400	4	10 x 35	350	5,000	2,000	5,000
50	7,200	18	10 x 40	400	13,750	8,200	13,750
100	14,000	35	10 x 40	400	26,050	14,950	26,050
200	28,000	70	10 x 40	400	64,200	28,500	64,200

* Filter rate approximately 5 gpm/ft^2.

** Seven foot diameter vertical pressure filters approximately 10 ft tall.

+ Rectangular space covering entire plant area.

‡ Entire plant enclosed.

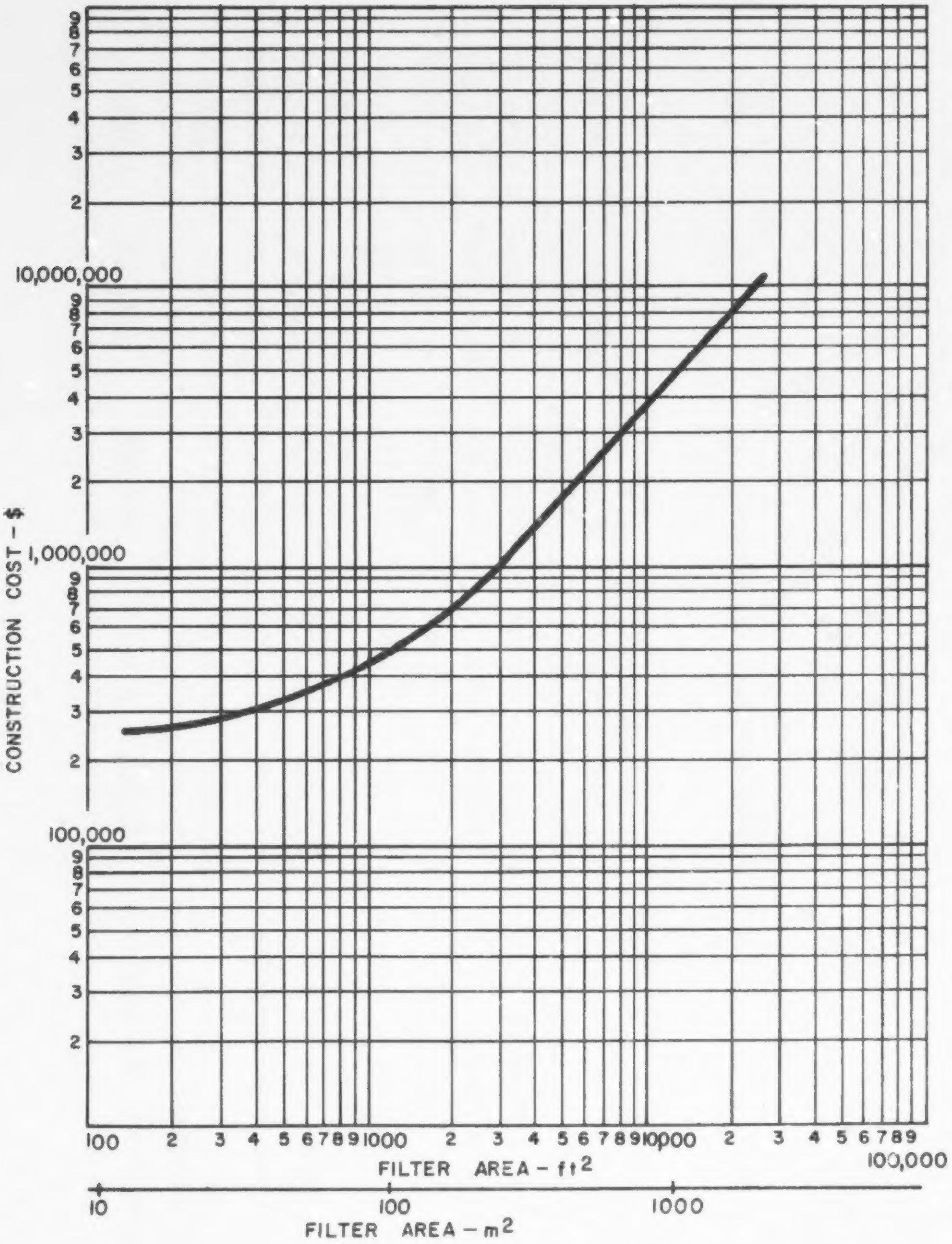


Figure 105. Construction cost for pressure filtration plants.

Table 86

Construction Cost for

Pressure Filtration Plants

Cost Category	Plant Capacity (mgd) and Filter Area (ft^2)				
	1 mgd, 140 ft^2	10 mgd, 1,400 ft^2	50 mgd, 7,200 ft^2	100 mgd, 14,000 ft^2	200 mgd 28,000 ft^2
Excavation and Sitework	$ 980	$ 1,730	$ 4,050	$ 7,990	$ 14,500
Manufactured Equipment	100,670	250,630	1,181,820	2,485,650	4,705,010
Concrete	690	940	4,710	9,410	17,650
Steel	290	500	2,510	5,010	10,020
Labor	9,620	24,510	184,990	369,970	739,950
Piping and Valves	23,630	70,900	635,640	1,271,290	2,542,580
Electrical and Instrumentation	20,080	51,720	298,130	614,310	1,188,810
Housing	65,970	62,870	211,620	368,200	686,810
SUBTOTAL	221,930	463,800	2,523,470	5,131,830	9,905,330
Miscellaneous and Contingency	33,290	69,570	378,520	769,770	1,485,800
TOTAL	255,220	533,370	2,901,990	5,901,600	11,391,130

Labor requirements were based on review of records from operating plants.

Table 87 and Figures 106 and 107 present operation and maintenance costs.

IN-PLANT PUMPING

Construction Cost

Construction cost estimates were developed for in-plant pumping facilities with capacities between 1 and 100 mgd. The pumps utilized were constant speed, vertical turbine pumps driven by drip-proof, high-thrust, vertical motors. The pumps are capable of pumping against total dynamic heads up to about 75 ft. A standby pump and motor was included for each installation. The estimates include a wet well and valving and piping to connect the pumps to a common manifold. Piping was sized for a velocity of approximately 5 ft/second.

The costs that were developed were comparable for systems capable of pumping against total dynamic heads between 35 and 75 ft. Figure 108 and Table 88 present the construction cost.

Operation and Maintenance Cost

Process energy requirements were calculated for 35 ft and 75 ft TDH, using a motor efficiency of 90 percent and a pump efficiency of 85 percent. Maintenance material includes repair parts for pumps, motors, valves, and electrical starters and controls.

Labor requirements are based on operation and maintenance of the pumps, motors, and valving, plus maintenance of electrical controls.

Figures 109 and 110 present operation and maintenance requirements, and Table 89 summarizes these requirements.

WASH WATER STORAGE TANKS

Construction Cost

Where topography is favorable, elevated storage tanks may be utilized to supply filter wash water by gravity flow. Customarily, a minimum of 15 ft between the top of the filter wash trough and the bottom of the storage tank is provided, although the wash system hydraulics must be considered in selection of a minimum elevation difference.

Elevated tanks are erected in the field using factory-formed steel plates. Costs were developed for cylindrical tanks, 35 ft in overall height and painted both inside and out. The costs are based on the conceptual designs presented in Table 90. Tanks are covered and are furnished with access ladder, manholes, outlet/inlet, drain and overflow nozzles, and handrails around hatches and on ladders. The tanks are supported on an oil-impregnated sand cushion and by a concrete ring footing wall. A typical wash water storage tank is shown in Figure 111. Costs do not include pumping facilities or pipes for conveyance of water to the storage tank, or between the storage tank and the filter gallery.

Table 87

Operation and Maintenance Summary for Pressure Filtration Plants

		Energy (kw-hr/yr)					
Capacity (mgd)	Filter Area (ft^2)	Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1	140	215,460	35,597	251,057	$1,280	1,460	$23,410
10	1,400	205,200	330,316	535,516	7,800	2,920	53,070
50	7,000	841,320	1,652,776	2,494,096	27,800	8,760	190,220
100	14,000	1,533,870	3,303,155	4,837,025	48,110	11,680	310,020
200	28,000	2,924,100	6,606,310	9,530,410	85,520	20,440	575,830

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

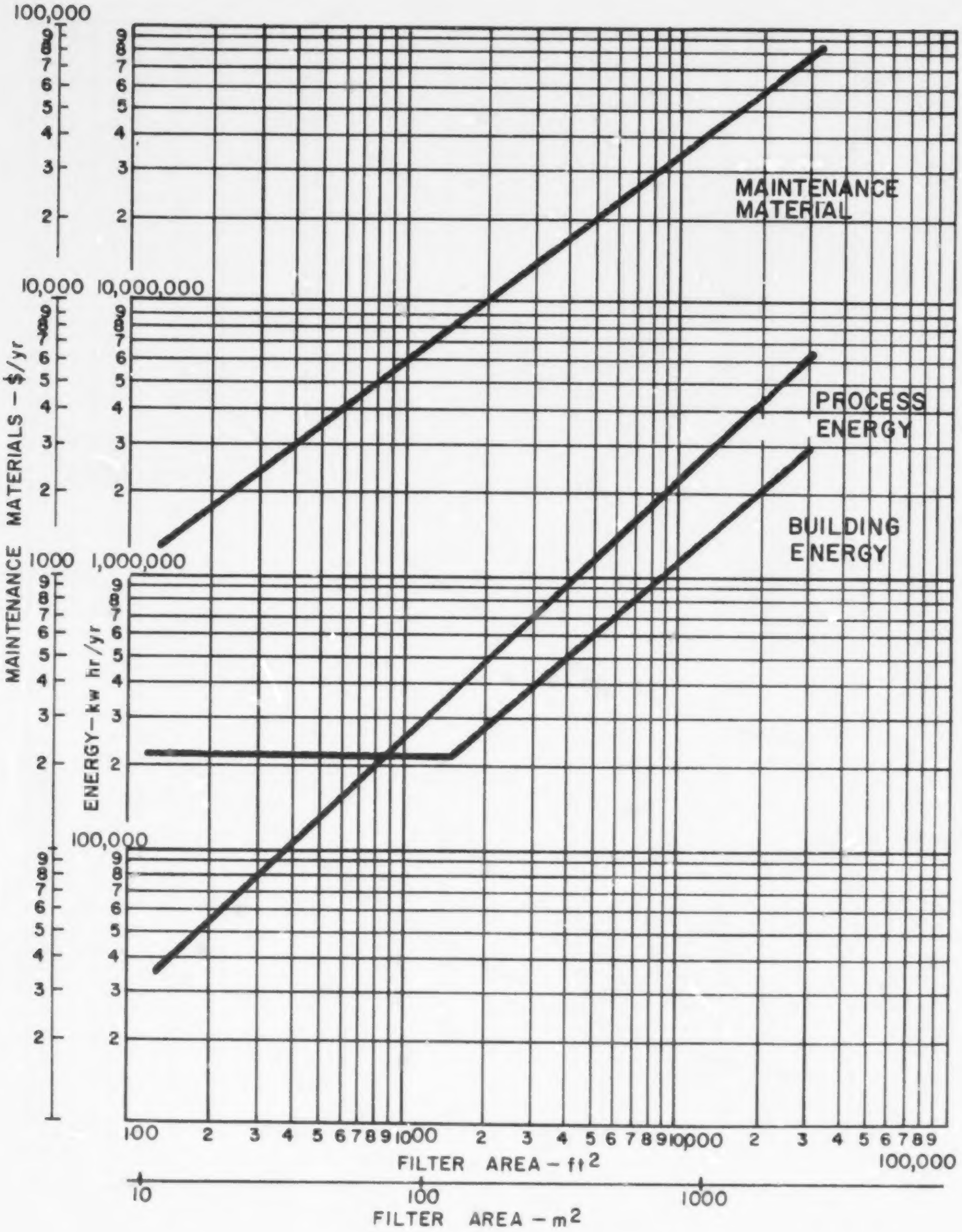


Figure 106. Operation and maintenance requirements for pressure filtration plants - building energy, process energy, and maintenance material.

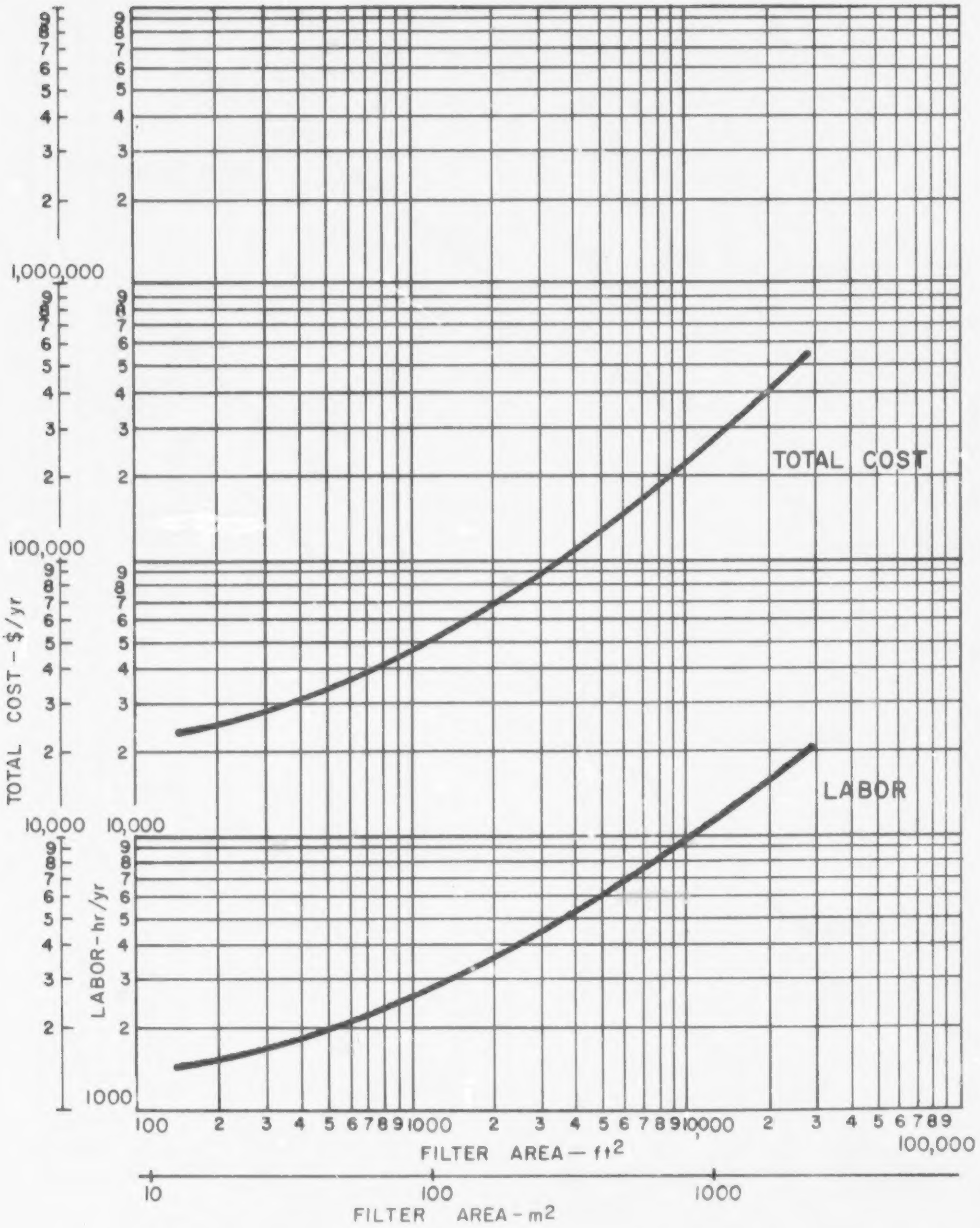


Figure 107. Operation and maintenance requirements for pressure filtration plants - labor and total cost.

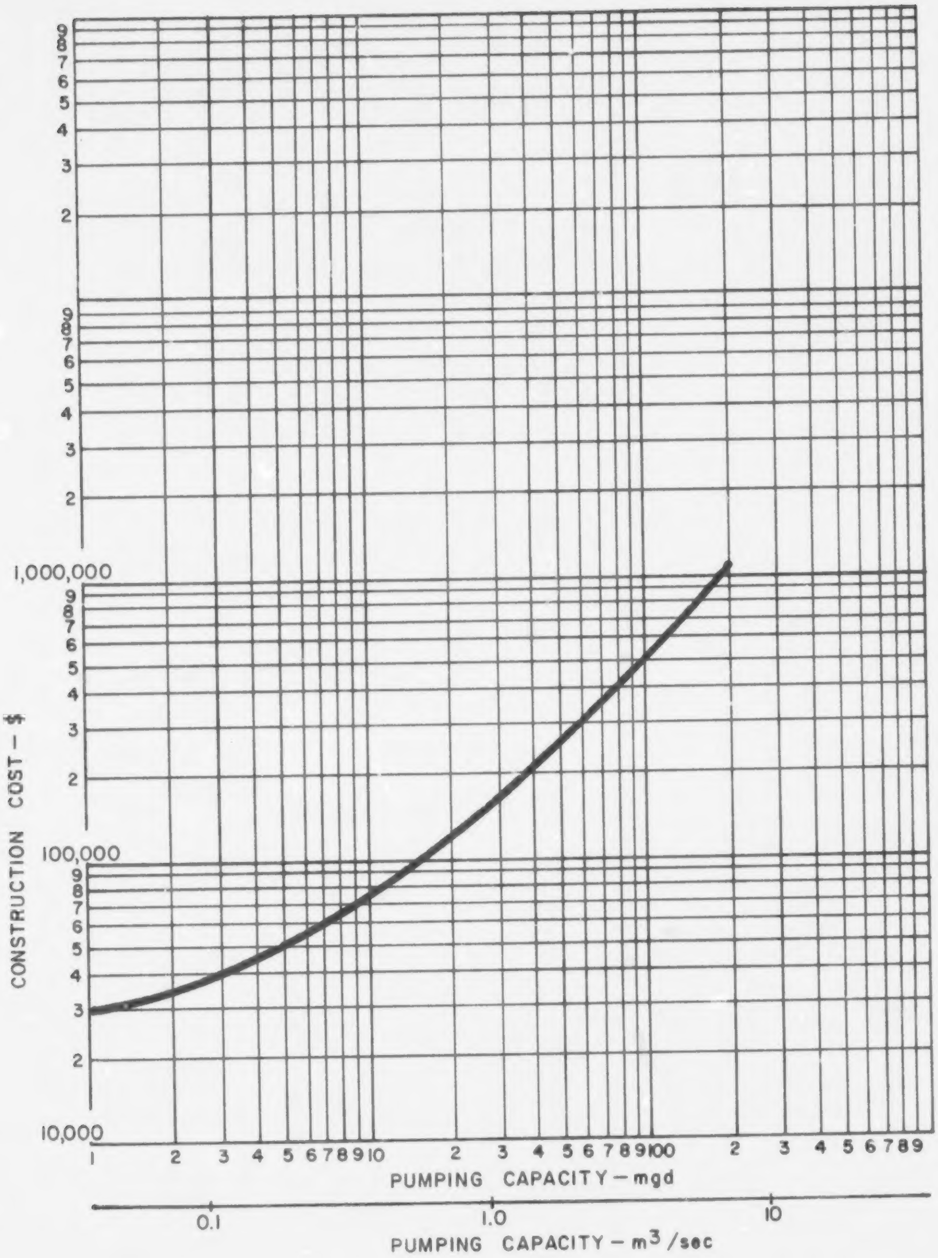


Figure 108. Construction cost for in-plant pumping.

Table 88

Construction Cost for In-Plant Pumping

Cost Category	Pumping Capacity (mgd)					
	1	5	10	50	100	200
Excavation and Sitework	$ 100	$ 100	$ 130	$ 360	$ 600	$ 1,030
Manufactured Equipment	6,300	9,110	14,780	48,650	83,400	152,900
Concrete	970	970	1,510	4,770	8,030	14,090
Steel	1,610	1,610	2,450	7,630	12,500	21,330
Labor	5,570	10,410	24,070	63,330	129,130	331,030
Pipe and Valves	5,090	12,330	16,300	60,230	114,200	222,080
Electrical & Instrumentation	3,170	4,930	7,390	25,760	47,240	89,360
Housing	1,500	1,500	3,000	14,520	28,830	58,080
SUBTOTAL	24,310	40,960	69,630	225,250	423,920	889,900
Miscellaneous & Contingency	3,650	6,140	10,440	33,790	63,590	133,490
TOTAL	27,960	47,100	80,070	259,040	487,510	1,023,390

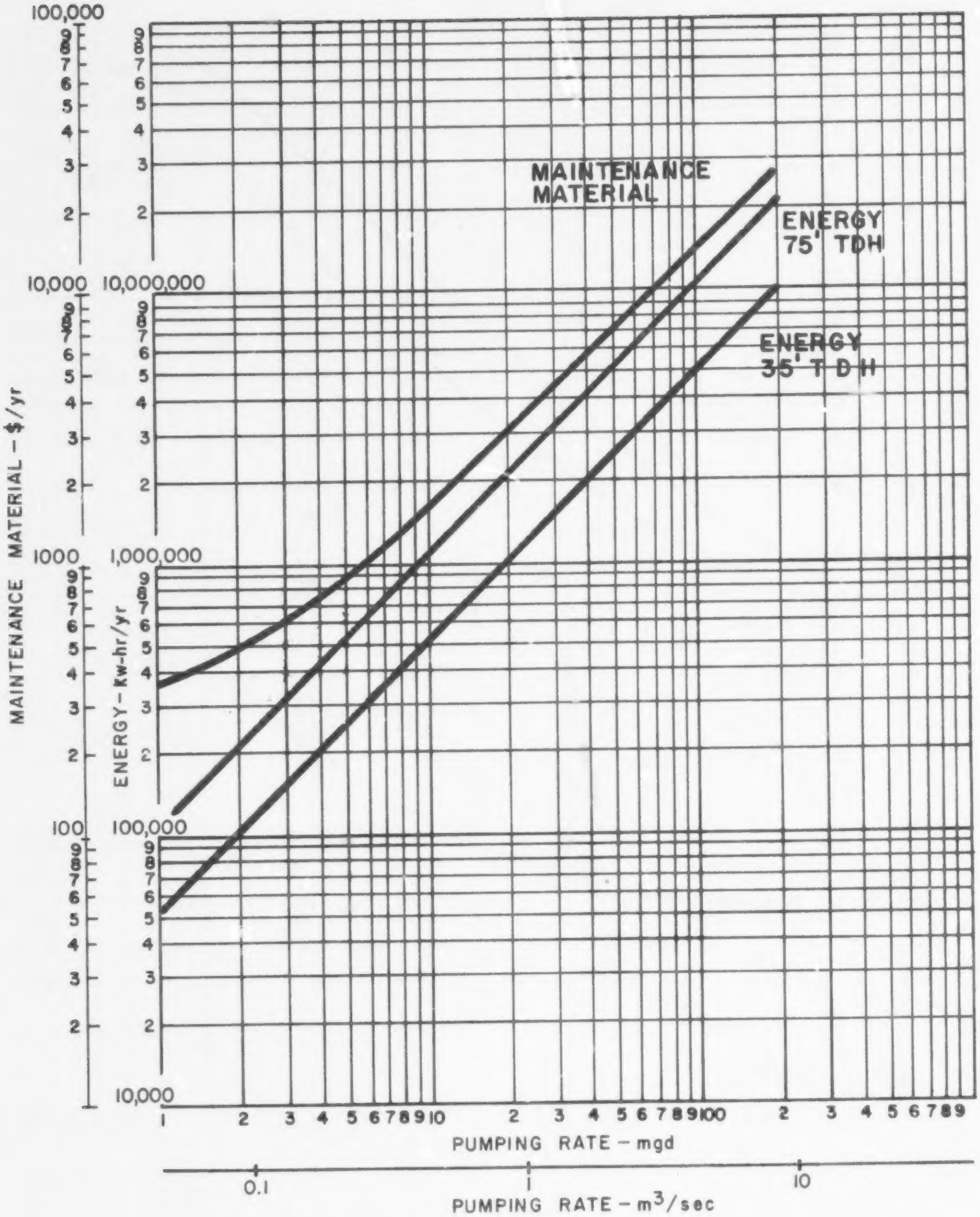


Figure 109. Operation and maintenance requirements for in-plant pumping - process energy and maintenance material.

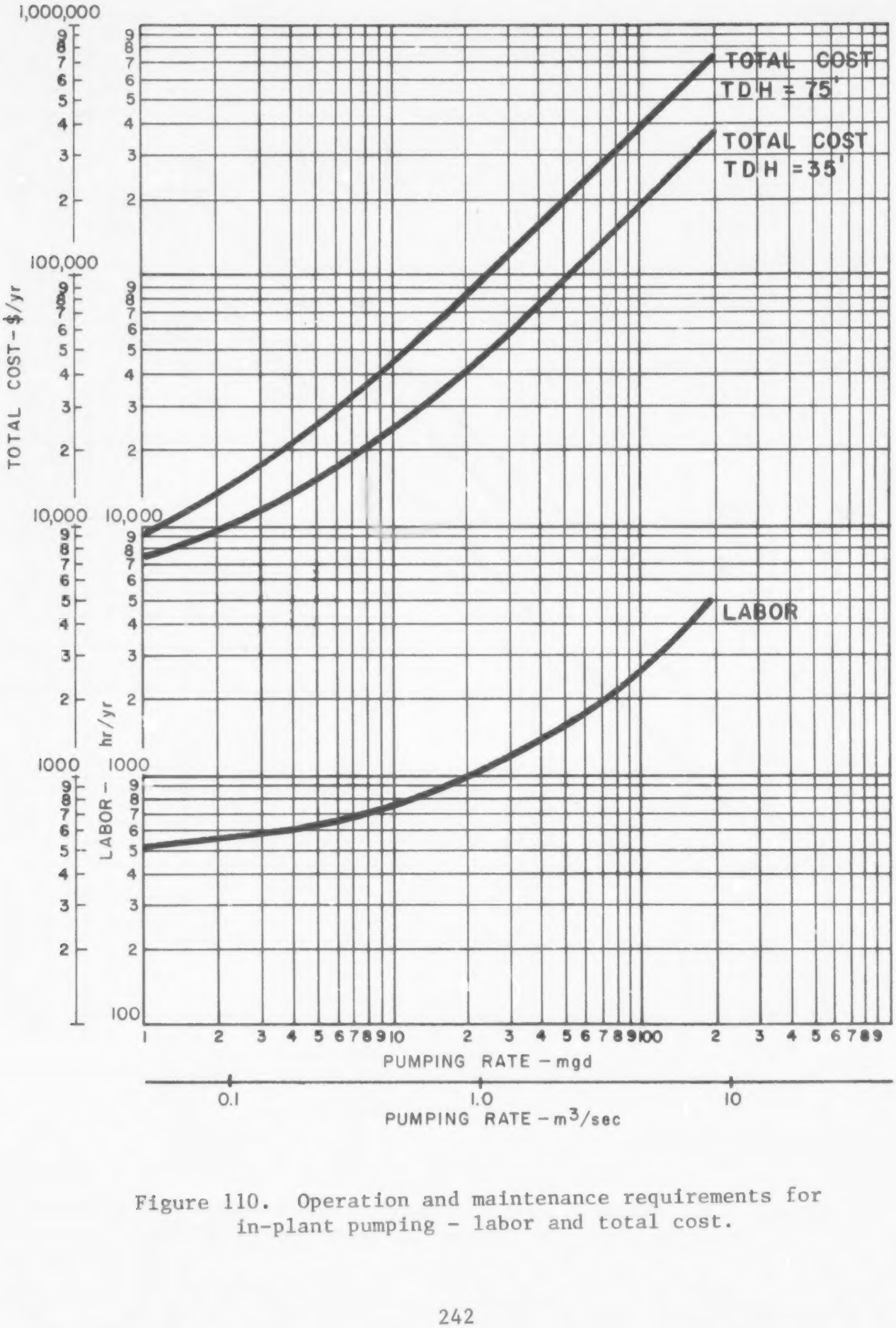


Figure 110. Operation and maintenance requirements for in-plant pumping - labor and total cost.

Table 89

Operation and Maintenance Summary

for In-Plant Pumping

Pumping Rate (mgd)	Process Energy (kw-hr/yr)		Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)	
	35' TDH	75' TDH			35' TDH	75' TDH
1	52,470	112,430	$ 350	520	$7,120	$8,920
5	262,330	562,130	850	630	15,020	24,010
10	524,650	1,124,250	1,600	740	24,740	42,730
50	2,623,250	5,621,250	8,000	1,540	102,100	192,040
100	5,246,500	11,242,500	15,000	2,690	199,300	379,180
200	10,493,000	22,485,000	25,000	5,130	391,090	750,850

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 90

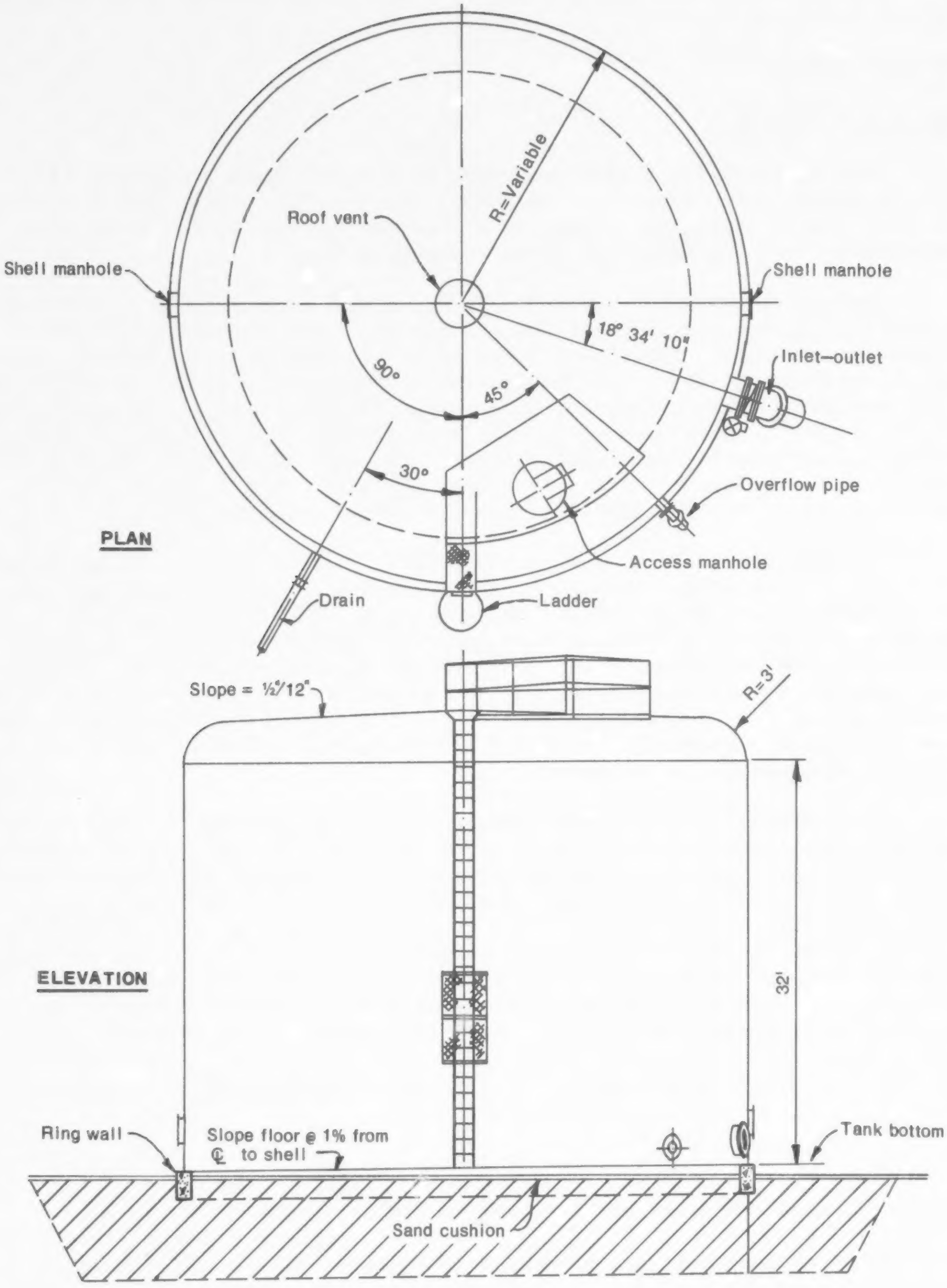
Conceptual Designs for

Wash Water Storage Tanks*

Storage Volume (gal)	Tank Dimensions (ft)		Number of Tanks
	Diameter[+]	Height	
21,000	11	35	1
105,000	24	35	1
450,000	50	35	1
900,000	50	35	2

*Tanks have domed roof, roof and shell access manways, inlet/outlet, drain overflow and vent-flanged nozzles, and caged access ladder with handrails around roof manway.

[+] Tanks less than 50 ft in diameter are fabricated of field-erected 3/16 in. plate, 50 ft tanks are fabricated from 1/4 in. tank.



Roof vent
R=Variable
Shell manhole
Shell manhole
18° 34' 10"
Inlet—outlet
90°
45°
30°
Overflow pipe
PLAN
Access manhole
Drain
Ladder
Slope = ½"/12"
R=3'
ELEVATION
32'
Ring wall
Slope floor @ 1% from ℄ to shell
Tank bottom
Sand cushion

Figure 111. Typical wash water storage tank.

Construction costs are presented for wash water storage tanks in Table 91 and Figure 112.

REVERSE OSMOSIS

Construction Cost

Reverse osmosis utilizes membranes to remove a high percentage of almost all inorganic ions, turbidity, bacteria, and viruses. Most organic matter is also removed, with the exception of several materials, including most halogenated and low molecular weight compounds.

Commercial units are available in sizes up to about 5,000 gpd for the membrane elements and up to 30,000 gpd for the reverse osmosis modules (pressure vessels). Therefore, large-scale plants would be composed of many small, parallel modules. Components taken into account in the construction cost estimates include housing, structural steel and miscellaneous metalwork. tanks, piping, valves, pumps, reverse osmosis membrane elements and pressure vessels, flow meters, cartridge filters, acid and polyphosphate feed equipment, and cleaning equipment. The cost curves are based on the use of either spiral-wound or hollow fine-fiber reverse osmosis membranes.

The efficiency of the membrane elements in reverse osmosis systems may be impaired by scaling because of slightly soluble or insoluble compounds, or by fouling as a result of the deposition of colloidal or suspended materials. Because of this, a very important consideration in the design of a reverse osmosis system is the provision of adequate pretreatment to protect the membrane from excessive scaling and fouling and to avoid frequent cleaning requirements. In the development of the cost curves, adequate pretreatment was assumed to precede the reverse osmosis process, and costs for pretreatment are not included in the estimates.

The construction cost curve applies to waters with a total dissolved solids (TDS) concentration ranging up to about 10,000 mg/l. Other considerations, such as calcium sulfate and silica concentrations and also the desired water recovery, affect costs more than the influent TDS concentration. The temperature of the feedwater is assumed to be between 65° and 95°F, and the pH of the feedwater is adjusted to about 5.5 to 6.0 before the reverse osmosis process. A single-pass treatment system (only one pass through the membrane) is assumed, with an operating pressure of 400 to 450 psi. The assumed water recoveries for different flow ranges are as follows:

Flow Range (mgd):	Water Recovery (%)
1 - 10	80
10 - 200	85

Brine disposal costs are not included in the estimates.

Construction costs are presented in Table 92 and also in Figure 113.

Table 91

Construction Cost for

Wash Water Storage Tanks

Cost Category	Storage Volume (gal)			
	21,000	105,000	450,000	900,000
Excavation & Site Work	$ 260	$ 730	$ 1,780	$ 3,180
Concrete	130	280	560	1,120
Steel	3,810	15,750	49,940	100,070
Labor	4,530	19,760	60,440	116,300
SUBTOTAL	8,730	36,520	112,720	220,670
Miscellaneous & Contingency	1,310	5,480	16,910	33,100
TOTAL COST	10,040	42,000	129,630	253,770

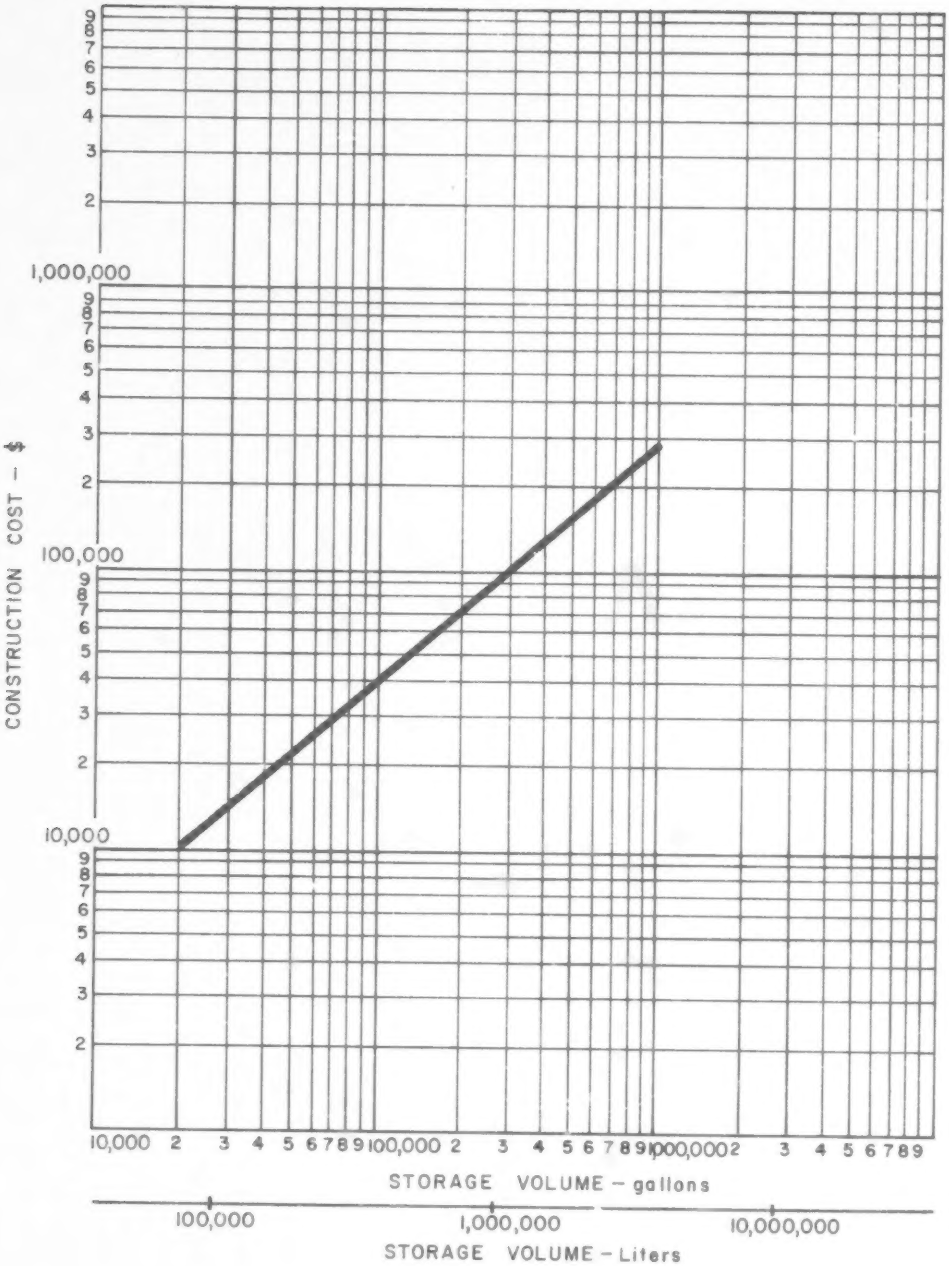


Figure 112. Construction cost for wash water storage tanks.

Table 92
Construction Cost for
Reverse Osmosis

Cost Category	Plant Capacity (mgd)			
	1.0	10	100	200
Manufactured Equipment	$474,210	$ 3,458,480	$29,174,260	$56,438,930
Labor	70,420	346,850	2,312,340	2,837,870
Electrical and Instrumentation	65,740	486,270	3,635,690	6,947,480
Housing	64,260	462,650	2,409,660	4,176,740
SUBTOTAL	674,630	4,754,250	37,531,950	70,401,020
Miscellaneous and Contingency	101,190	713,140	5,629,790	10,560,150
TOTAL	775,820	5,467,390	43,161,740	80,961,170

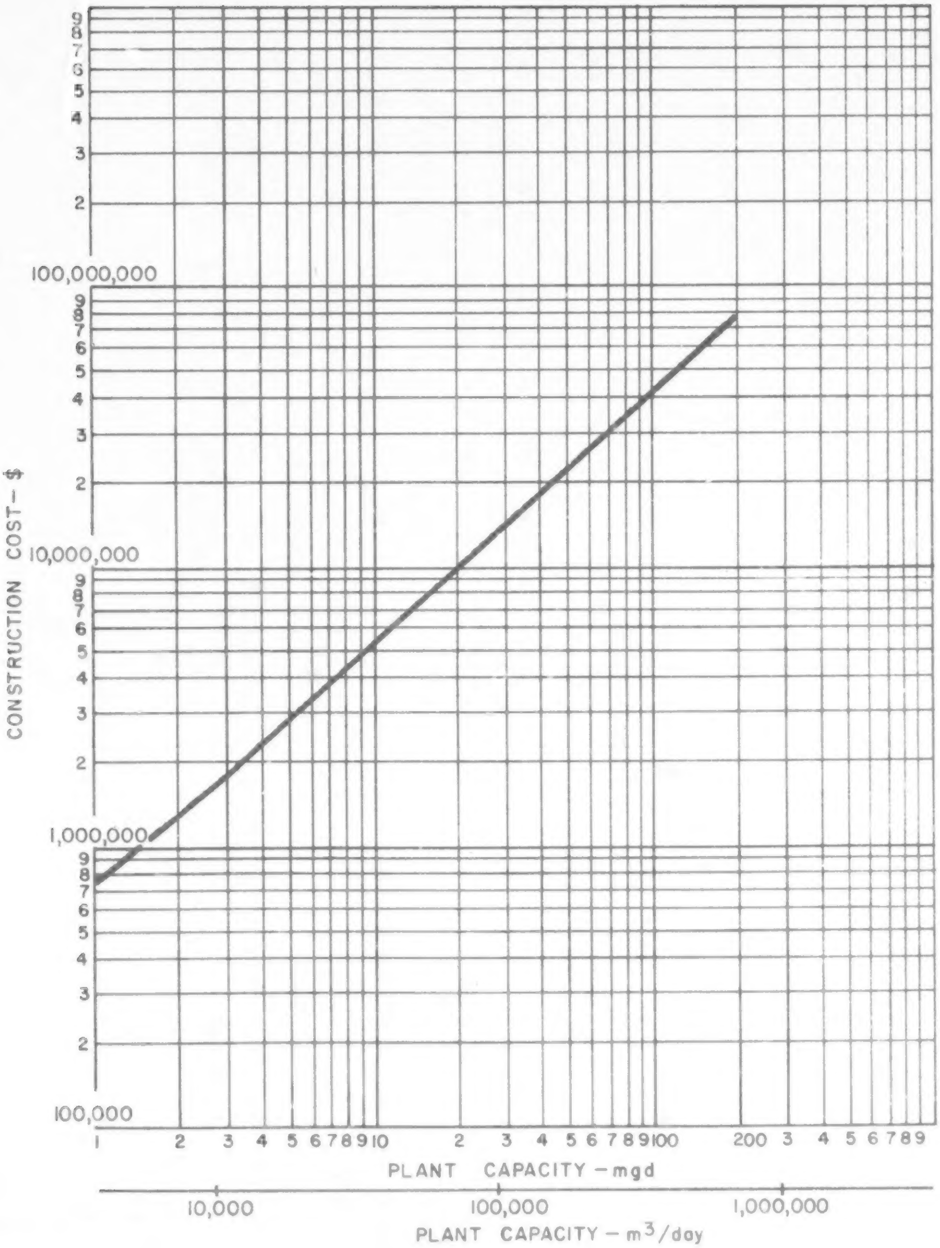


Figure 113. Construction cost for reverse osmosis.

Operation and Maintenance Cost

Electrical energy usage is included for the high-pressure feedwater pumps, based on an operating pressure of 450 psi and on the water recoveries listed in the construction cost write-up. For other pumps and chemical feed equipment, an energy usage of 10 percent of the usage for the high-pressure pumps was assumed. Electrical energy for lighting, heating, and ventilating was calculated based on an estimated floor area required for complete housing of the reverse osmosis equipment.

The largest maintenance material requirement is for membrane replacement; a membrane life of 3 years was used in the cost estimates. Other maintenance material requirements are for replacement of cartridge filters, for membrane cleaning chemicals, and for materials needed for periodic repair of pumps, motors, and electrical control equipment. The maintenance material costs vary from 17.5 ¢/1,000 gal for plants above 10 mgd to 25 ¢/1,000 gal for plants below 1 mgd. Costs for pretreatment chemicals such as acid and polyphosphate are not included in the estimates. The chemicals utilized and the dosages required will show great variability between different water supplies and should be determined from pilot plant testing.

Labor requirements are for cleaning and replacing membranes, replacing cartridge filters, maintaining the high pressure and other pumps, preparing treatment chemicals and determining proper dosages, maintaining chemical feed equipment, and monitoring performance of the reverse osmosis membranes. Membrane cleaning was assumed to occur monthly. In estimating labor requirements, a minimum of about 1.5 hr/day of labor was assumed for the smallest plant.

Operation and maintenance requirements are summarized in Table 93 and illustrated in Figures 114 and 115.

ION EXCHANGE - SOFTENING

Construction Cost

Cation exchange resins can be utilized for the removal of not only hardness, but also other constituents such as barium, trivalent chromium, lead, manganese, mercury, and radium. Pressure units are generally competitive with gravity units at low capacities, but gravity units are more economical at higher flows. An advantage of pressurized exchange units is the capability of pumping through the softener and directly to the clearwell, or other point, possibly eliminating the need for double pumping.

Facilities were sized on an exchange capacity of 20 kilograins/ft^3 and a hardness reduction of 300 mg/l. Regeneration facilities were sized on the basis of 150 bed volumes treated before regeneration and a regenerant requirement of 0.275 lb of sodium chloride/kilograin of exchange capacity. The total regeneration time required in 50 min. Of this time, 10 min is for backwash, 20 min is for regeneration brine contact time (brining and displacement rinse), and 20 min is a fast rinse at 1.5 gpm/ft^3. Feedwater was

Table 93

Operation and Maintenance Summary for Reverse Osmosis

Plant Capacity (mgd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
1.0	105,400	2,409,000	2,514,400	$ 97,280	1,840	$ 191,100
10	840,000	22,082,500	22,922,500	748,340	2,840	1,464,420
100	7,560,000	220,825,000	228,385,000	6,831,280	6,670	13,749,530
200	15,120,000	441,650,000	456,770,000	13,683,940	11,550	27,502,540

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

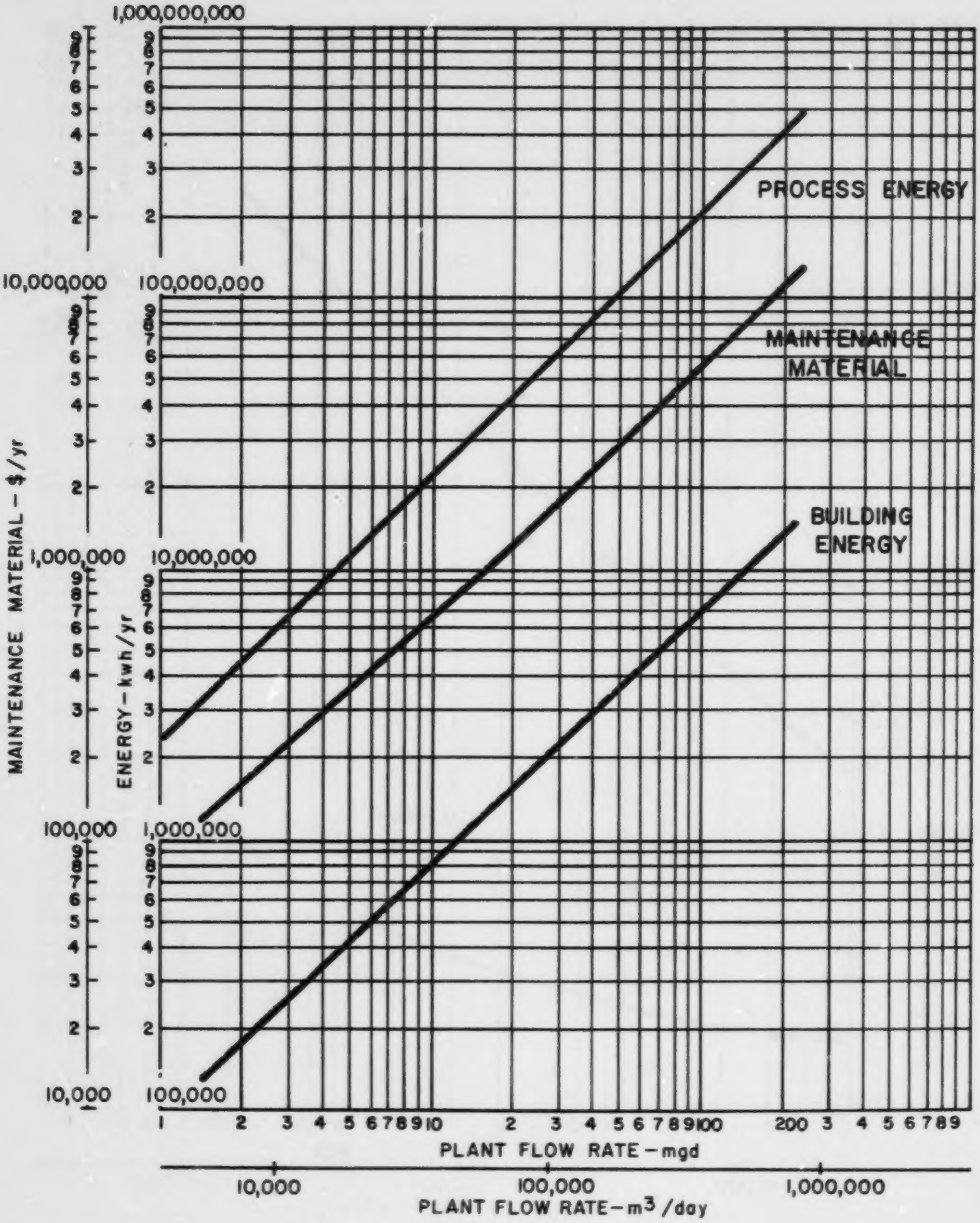


Figure 114. Operation and maintenance requirements for reverse osmosis - building energy, process energy, and maintenance material.

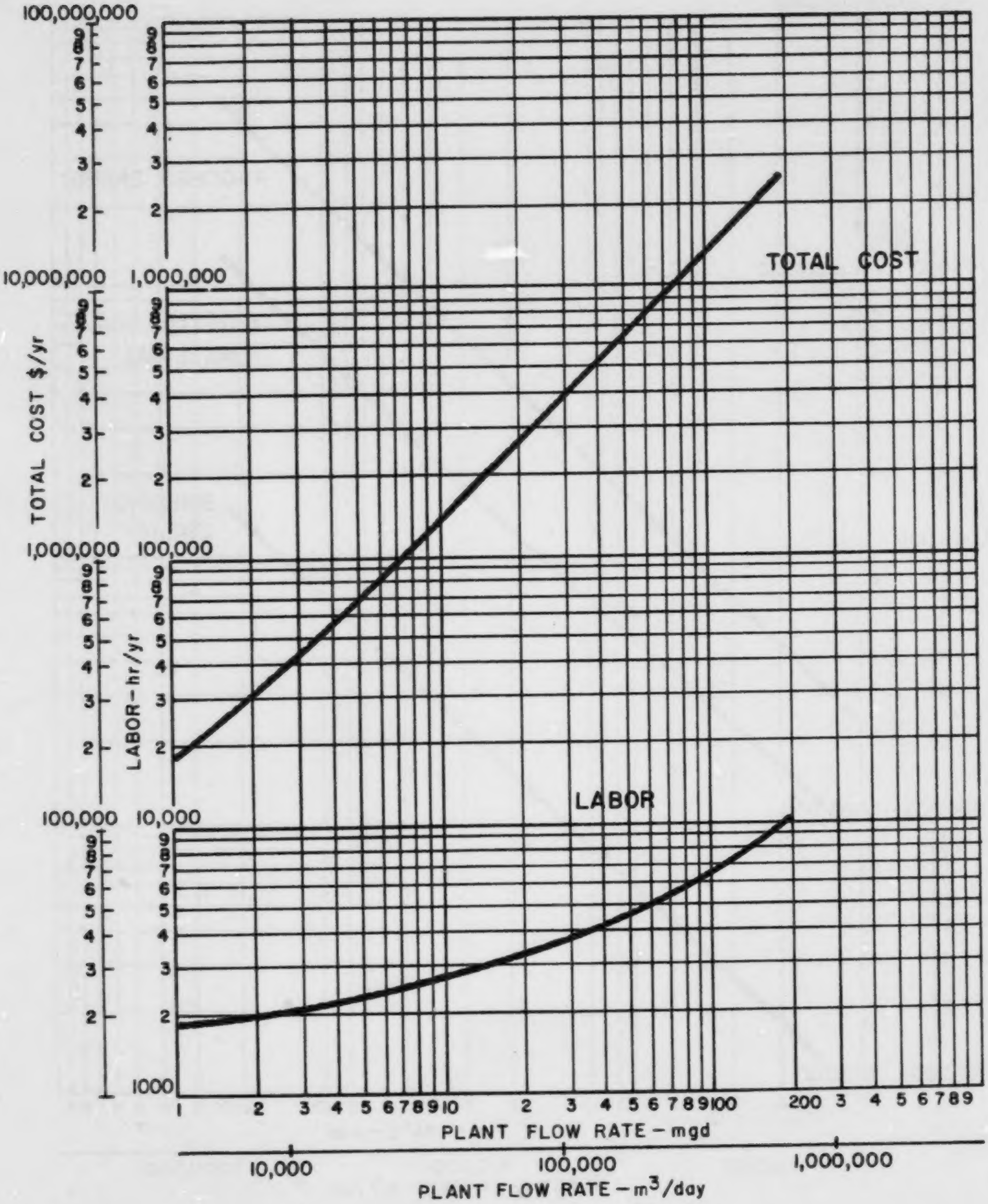


Figure 115. Operation and maintenance requirements for reverse osmosis - labor and total cost.

assumed to be of sufficient clarity to require backwashing only for resin reclassification. Backwash pumping facilities and media installation are included in the construction cost. In-place resin costs of $45.00/ft^3 were utilized.

No facilities are included in the construction cost for spent brine disposal.

Pressure Ion Exchange Softening--

Construction costs were developed for pressure ion exchange using the conceptual information presented in Table 94. The contact vessels are fabricated steel with a baked phenolic lining added after fabrication, and constructed for 100 psi working pressure. The depth of resin was 8 ft, and the contact vessel was designed to allow for as much as 80 percent media expansion during backwash. A gravel layer between underdrains and media was not included.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures, constructed with the top foot above ground level. Saturated brine withdrawal from the salt storage/brining basins is 26 percent by weight. A saturated brine storage of 2.5 days of normal use was provided in the storage/brining basins. Pumping facilities were included to pump from the brining tanks to the contact vessels. An eductor is utilized to add sufficient water to dilute the brine to a 10-percent concentration as it is being transferred from the salt storage/brining tank to the contact vessel.

Construction costs for pressure ion exchange softening are presented in Figure 116 and summarized in Table 95.

Gravity Ion Exchange Softening--

Construction costs were developed for gravity ion exchange using the conceptual designs presented in Table 96. The structures are similar to those used for gravity filtration, but they have larger influent channels to allow a higher loading per square foot of surface area and they use an 18-ft wall depth to allow a loading of 8 gpm/ft^2. An 8-ft resin depth was utilized, and underdrains not requiring an overlying gravel layer were utilized. Piping was modified from gravity filtration by the addition of a regenerant line. Facilities included for regenerant storage and dilution to 10 percent were similar to those described for pressure ion exchange.

Construction costs for gravity ion exchange softening are presented in Figures 116 and in Table 97.

Operation and Maintenance Cost

Electrical requirements are for regenerant pumping, rinse pumping, backwash pumping, and building heating, lighting, and ventilation. Backwash pumping was based on a 10-min wash period at 8 gpm/ft^2. Regenerant pumping was based on a regeneration rate of 7 gal/min per ft^3 of resin and a regeneration time of 20 min rinse at a rate of 30 gal/ft^3 of media. All pumping was assumed to be

Table 94

Conceptual Design for

Pressure Ion Exchange Softening

Plant Capacity (mgd)	Number of Contactors	Diameter of Contactors (ft)	Housing (ft^2)	Total Salt Storage - Brining Capacity (ft^3)
1.1	2	8	558	918
3.7	3	12	1,232	3,146
6.1	5	12	1,980	5,244
12.3	10	12	3,960	10,488
49	40	12	15,840	41,954
122.6	100	12	31,680	104,890

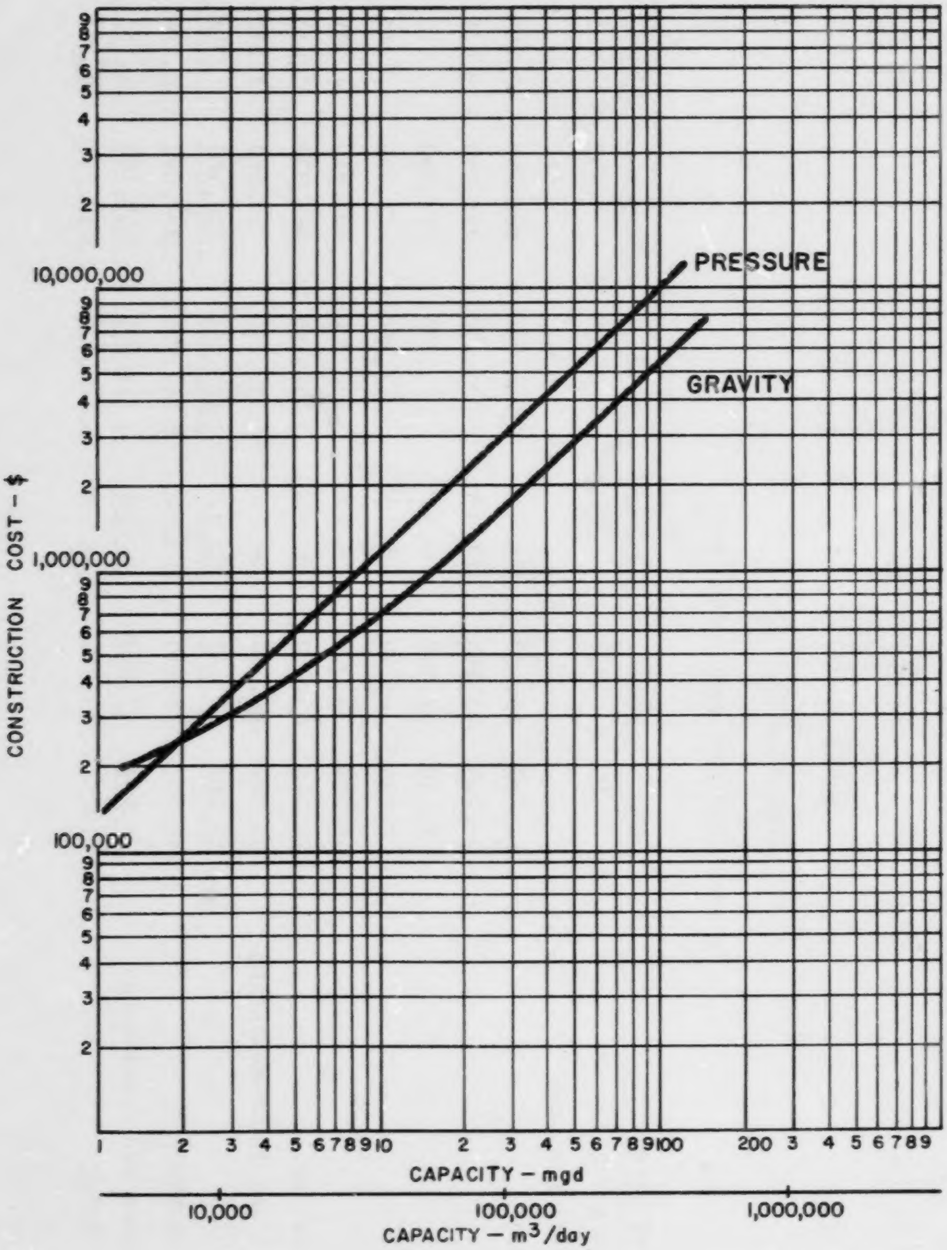


Figure 116. Construction cost for pressure and gravity ion exchange softening.

Table 95

Construction Cost for

Pressure Ion Exchange Softening

Cost Category	Plant Capacity (mgd)					
	1.1	3.7	6.1	12.3	49.0	122.6
Excavation and Sitework	$ 410	$ 820	$ 1,090	$ 2,190	$ 4,490	$ 9,220
Manufactured Equipment						
Equipment	24,830	65,200	110,430	220,160	880,760	2,203,390
Resin	28,790	97,190	161,980	323,970	1,295,850	3,238,400
Concrete	1,340	2,640	3,510	7,020	13,860	27,850
Steel	2,130	4,180	5,530	11,060	21,700	43,600
Labor	14,050	32,000	54,450	108,830	407,910	1,019,880
Pipe and Valves	15,140	43,210	82,880	165,760	663,030	1,417,630
Electrical and Instrumentation	33,190	48,680	81,550	192,210	716,590	1,819,780
Housing	19,280	35,070	62,220	113,250	390,200	763,590
SUBTOTAL	139,160	328,990	563,640	1,144,450	4,394,390	10,543,340
Miscellaneous and Contingency	20,870	49,350	84,550	171,670	659,160	1,581,500
TOTAL	$160,030	378,340	648,190	1,316,120	5,053,550	12,124,840

Table 96

Conceptual Design for Gravity Ion Exchange Softening

Plant Capacity (mgd)	Number of Beds	ft^2/Bed	Housing (ft^2)	Total Salt Storage and Brining Capacity (ft^3)
1.5	2	70	150	1,300
7.5	4	175	420	6,490
15	4	350	800	12,990
75	10	700	2,900	64,930
150	14	1,000	4,060	129,850

Table 97

Construction Cost for
Gravity Ion Exchange Softening

Cost Category	Plant Flow Rate (mgd) 1.5	7.5	15	75	150
Excavation and Sitework	$3,670	$6,500	$9,720	$ 33,250	$ 57,920
Manufactured Equipment					
Equipment	43,560	93,880	146,160	559,210	1,018,490
Resin	40,000	200,720	401,010	2,005,070	4,010,130
Concrete	9,270	21,320	32,400	104,220	139,280
Steel	9,340	18,120	25,720	92,290	160,410
Labor	22,390	58,080	81,250	299,240	511,350
Pipe and Valves	23,140	64,890	89,350	262,240	393,490
Electrical and Instrumentation	20,090	57,620	57,620	148,710	253,260
Housing	17,400	40,480	70,590	291,940	514,330
SUBTOTAL	188,860	561,610	913,820	3,796,170	7,058,660
Miscellaneous and Contingency	28,330	84,240	137,070	569,430	1,058,800
TOTAL	217,190	645,850	1,050,890	4,365,600	8,117,460

against a 25-ft TDH. Feed water pumping costs are not included.

Maintenance material costs for periodic repair and replacement of components were estimated based on 1 percent of the construction cost. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity because of chemical fouling. A 3-percent annual loss of resin capacity because of physical and chemical causes is typical for cation resins. In addition, the resin must be completely replaced every 8 to 10 years. To account for this loss of resin and the required replacement, an annual cost equivalent to 13 percent of the resin cost is also included in the maintenance material. No costs are included for regenerant.

Labor requirements are for operation and maintenance of the ion exchange vessels and the pumping facilities. Hours were estimated based on filtration plants and filter pumping facilities of comparable size. Labor requirements are also included for periodic media addition and replacement of the media every 8 to 10 years.

No costs are included for spent brine disposal. Operation and maintenance requirements are presented in Figures 117 to 120 and are summarized in Tables 98 and 99 for pressure and gravity ion exchange softening.

PRESSURE ION EXCHANGE - NITRATE REMOVAL

Construction Cost

Strongly basic anion exchange resins may be used for the removal of nitrates, and also sulfates, fluorides, and some forms of organic and inorganic mercury. When a strongly basic anion exchanger is operated on the chloride form, the sulfate is selectively removed over nitrate, and the nitrate is selectively removed over fluoride. Therefore, the larger the nitrate-to-sulfate raio, the greater is the nitrate removal capacity of the resin. Generally, fluoride removal by anion exchange resins is not considered practical because of the low capacity.

Costs were developed for treatment of a water supply with the following anion content: nitrate = 100 mg/l; sulfate = 80 mg/l; other anions = 120 mg/l. The assumed nitrate capacity for the strongly basic anion exchange resin operated on the chloride form was 7 kilograins of nitrate/ft^3, when operated to nitrate breakthrough. It must be noted that other quality water supplies may result in significantly different exchange capacities, and pilot-scale studies are recommended before design. A sodium chloride regenerant was utilized, with a regenerant requirement of 15 lb/ft^3 resin.

A total regeneration time of 54 min was utilized. Backwash required 10 min, the brine contact and displacement rinse, 24 min, and the fast rinse, an additional 20 min.

Construction costs were developed for pressure anion exchange, using fabricated steel contact vessels with a 100-psi working pressure and a baked phenolic lining. A 6-ft bed depth was utilized, although tanks were sized for up to 80 percent resin expansion during backwash. A gravel layer between

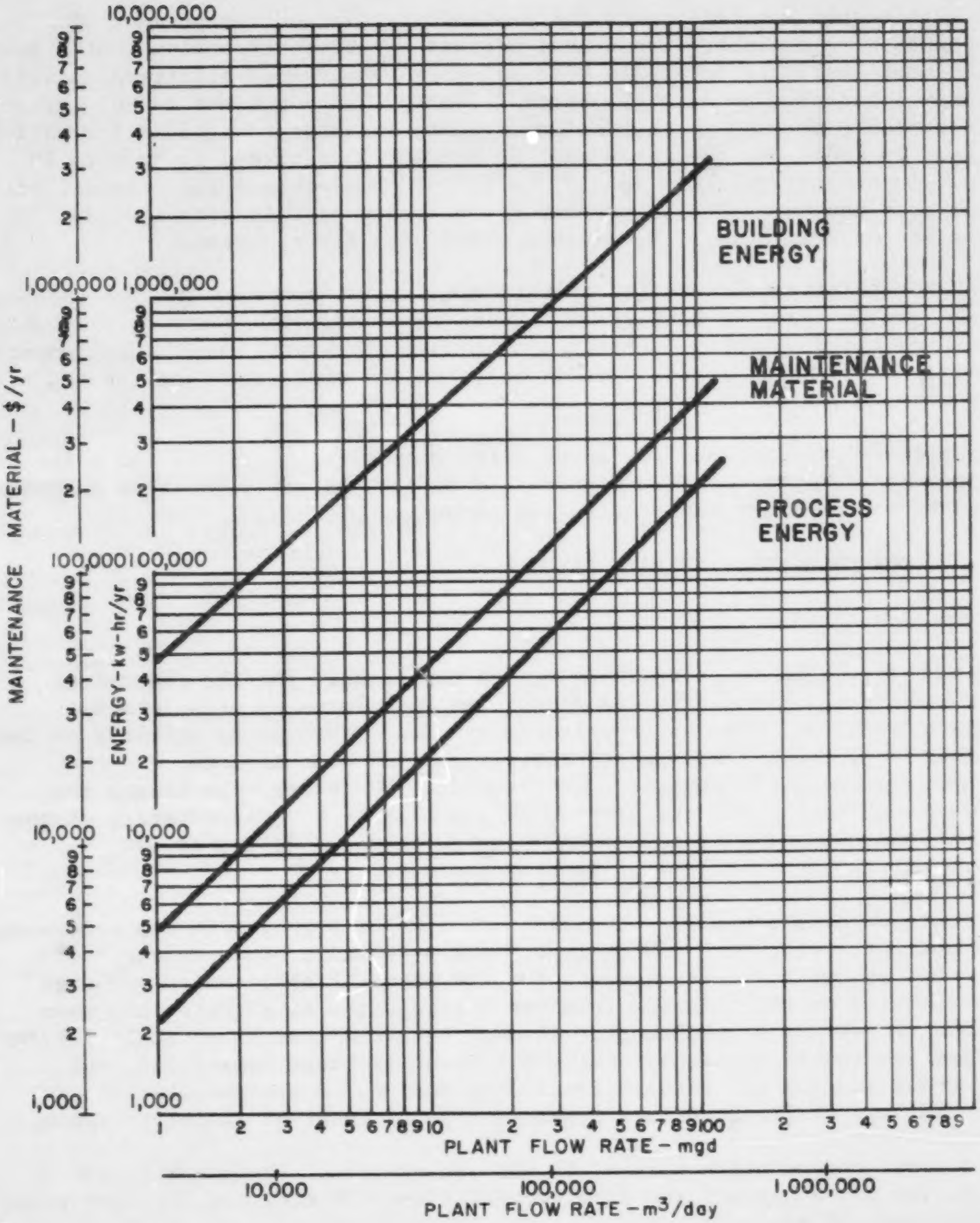


Figure 117. Operation and maintenance requirements for pressure ion exchange softening - building energy, process energy and maintenance material.

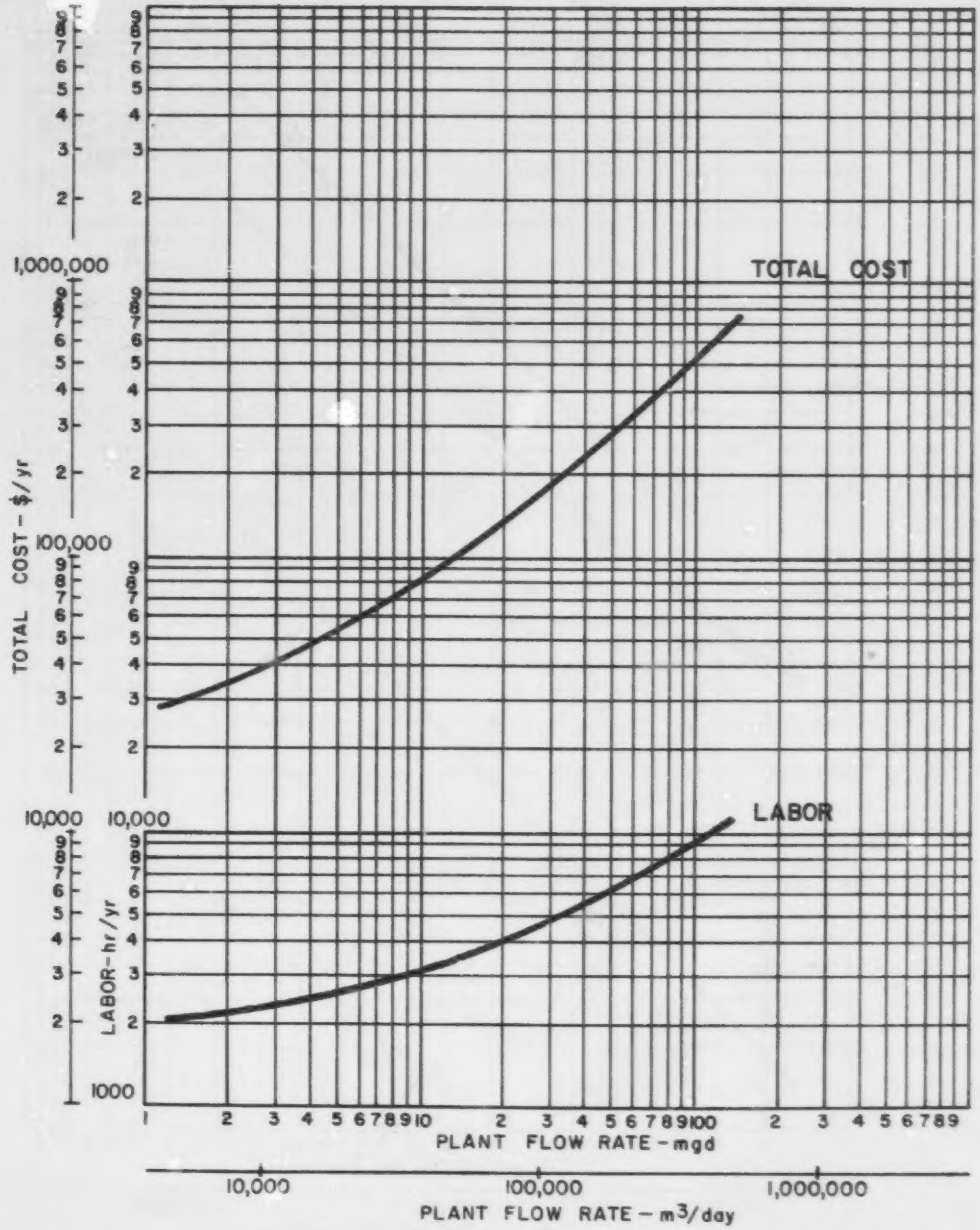


Figure 118. Operation and maintenance requirements for pressure ion exchange softening - labor and total cost.

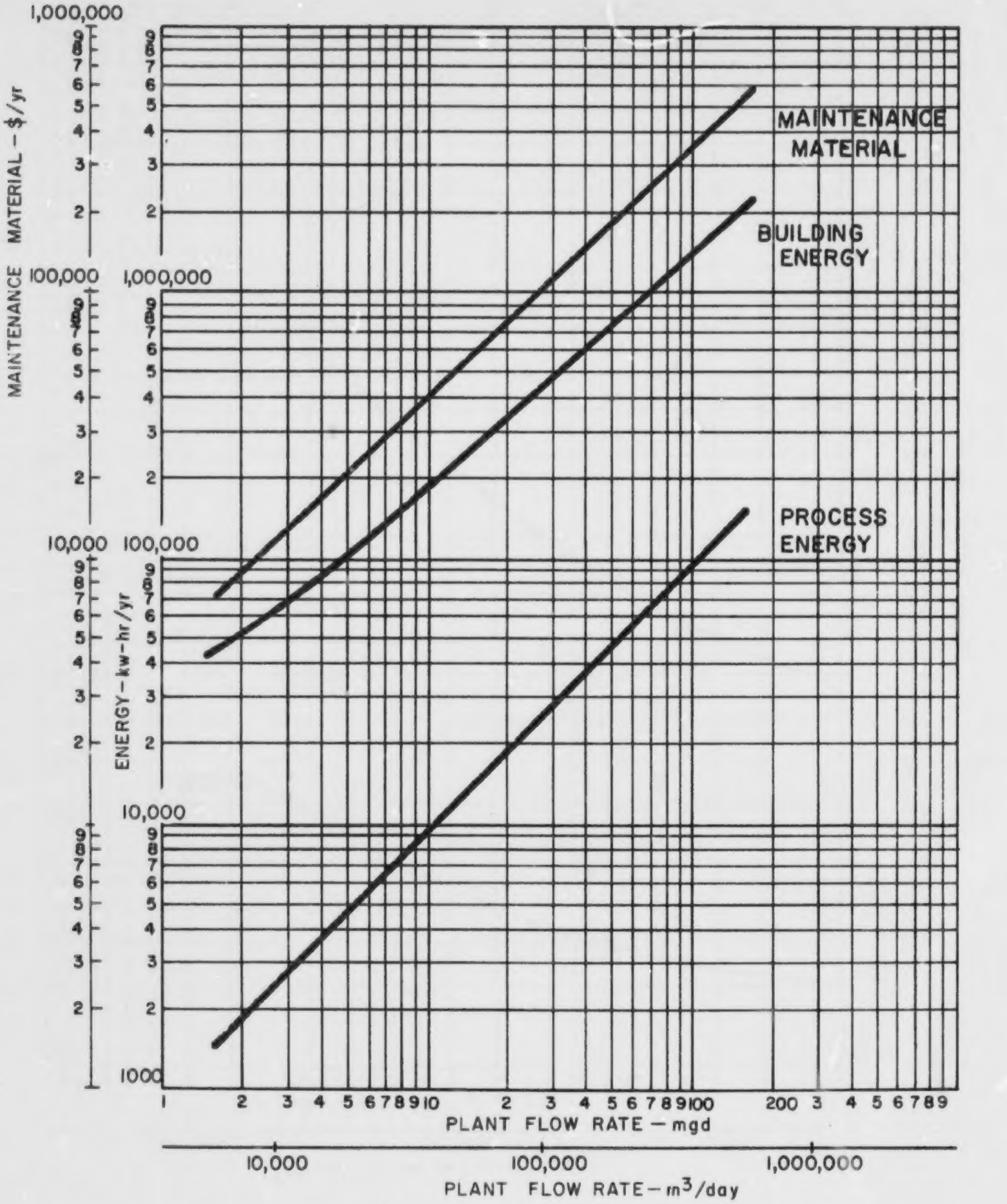


Figure 119. Operation and maintenance requirements for gravity ion exchange softening - building energy, process energy, and maintenance material.

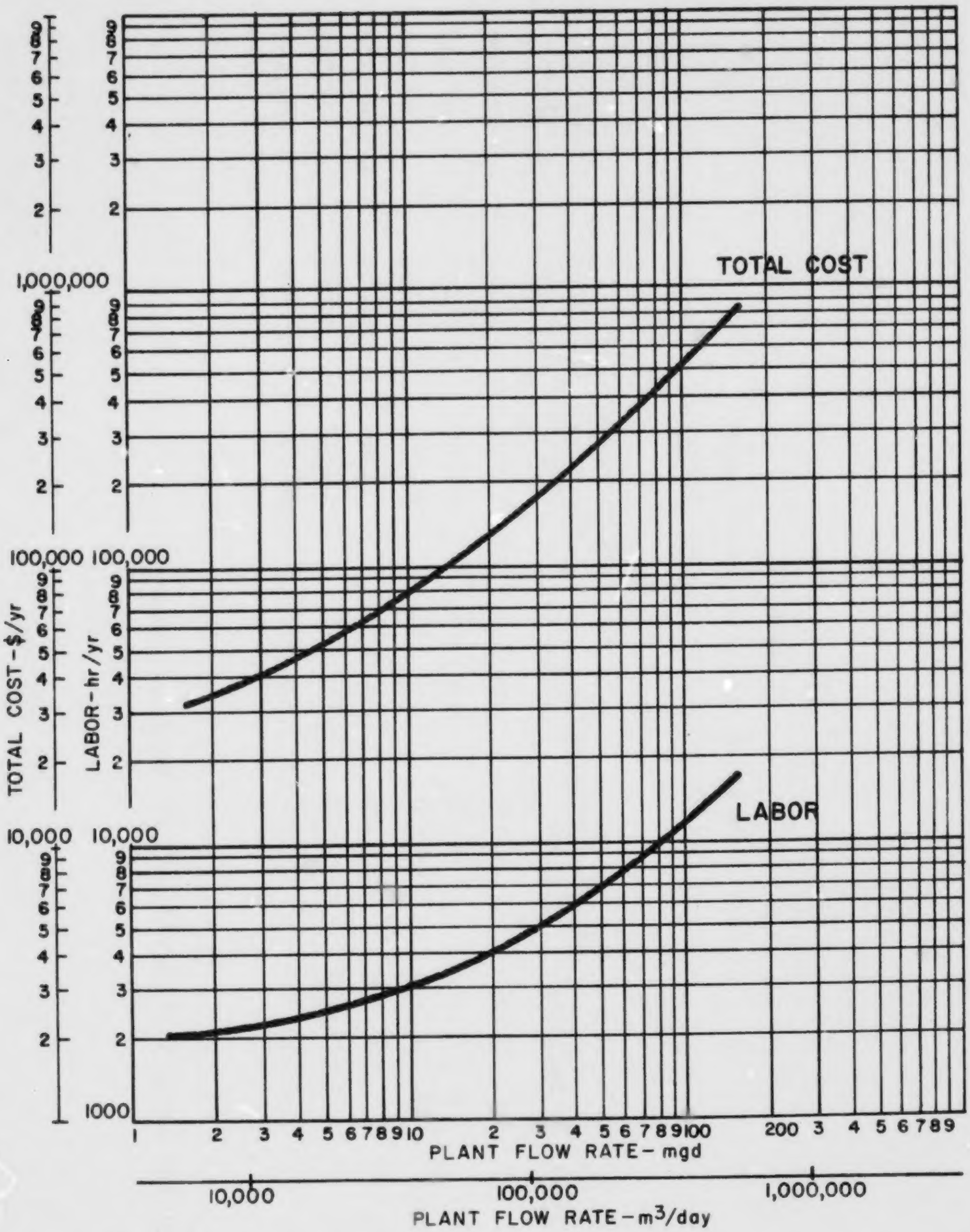


Figure 120. Operation and maintenance requirements for gravity ion exchange softening - labor and total cost.

Table 98

Operation and Maintenance Summary for Pressure Ion Exchange Softening

Plant Flow Rate (mgd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
1.1	57,250	2,270	59,520	$ 5,010	2,160	$28,400
3.7	126,400	7,620	134,020	16,190	2,700	47,210
6.1	203,150	12,570	215,720	26,770	3,000	63,240
12.3	406,300	25,350	431,650	53,260	3,400	100,210
49	1,625,180	100,970	1,726,150	211,560	6,900	332,340
122.6	3,250,370	252,630	3,503,000	523,070	13,600	764,160

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 99

Operation and Maintenance Summary for Gravity Ion Exchange Softening

Plant Flow Rate (mgd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
1.5	44,120	1,470	45,590	$ 7,440	2,230	$ 31,110
7.5	151,850	7,370	159,220	32,810	3,090	68,490
15	279,070	14,730	293,800	63,120	3,570	107,630
75	1,190,160	73,700	1,263,860	306,640	9,600	440,560
150	2,165,890	147,310	2,313,200	607,100	17,460	851,100

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

the resin and the underdrains was not utilized. Resin placement and backwash pumping costs are included in the construction cost.

Regeneration facilities include two salt storage/brining basins, which are open, reinforced concrete structures constructed with the top foot above ground level. Saturated brine withdrawn from the salt storage/brining basins is 26 percent by weight. A saturated brine storage of 2.5 days normal use was provided in the storage brining/basins. Pumping facilities were included to pump from the brining tanks to the contact vessels. An eductor is utilized to add sufficient water to dilute the brine to a 10 percent concentration as it is being transferred from the salt storage/brining tank to the contact vessel.

Conceptual designs that were used to estimate costs are presented in Table 100.

Table 100

Conceptual Designs for

Pressure Ion Exchange Nitrate Removal

Plant Capacity (mgd)	Number of Contactors	Diameter of Contactors (ft)	Housing (ft^2)
1.2	2	8	930
3.9	3	12	2,375
6.5	5	12	3,910
13	10	12	6,920

No facilities are included in the construction cost for disposal of spent regenerant. Construction costs for pressure ion exchange nitrate removal are presented in Figures 121 and summarized in Table 101.

Operation and Maintenance Cost

Electrical energy costs are for backwash pumping, rinse pumping, regenerant pumping, and building heating, lighting, and ventilation. Backwash pumping was based on a 10-min wash at 3 gpm/ft^2. Regenerant pumping was based on a rate of 1 gal/min per ft^3 of resin for 24 min, and fast rinse pumping was based on a rate of 8 gal/min per ft^2 for 20 min. All pumping was assumed to be against a 25 ft TDH.

Maintenance material costs for periodic repair and replacement of components were estimated based on 1 percent of the construction cost. Resin replacement costs are for resin lost annually by physical attrition as well as loss of capacity as a result of chemical fouling. As anion resin is typically replaced every 3 to 5 years, a 25 percent annual resin replacement was included to account for resin fouling and resin loss. Regenerant costs are not included in the maintenance material cost.

Labor requirements are for operation and maintenance of ion exchange vessels and the pumping facilities. Hours were estimated based on filtration

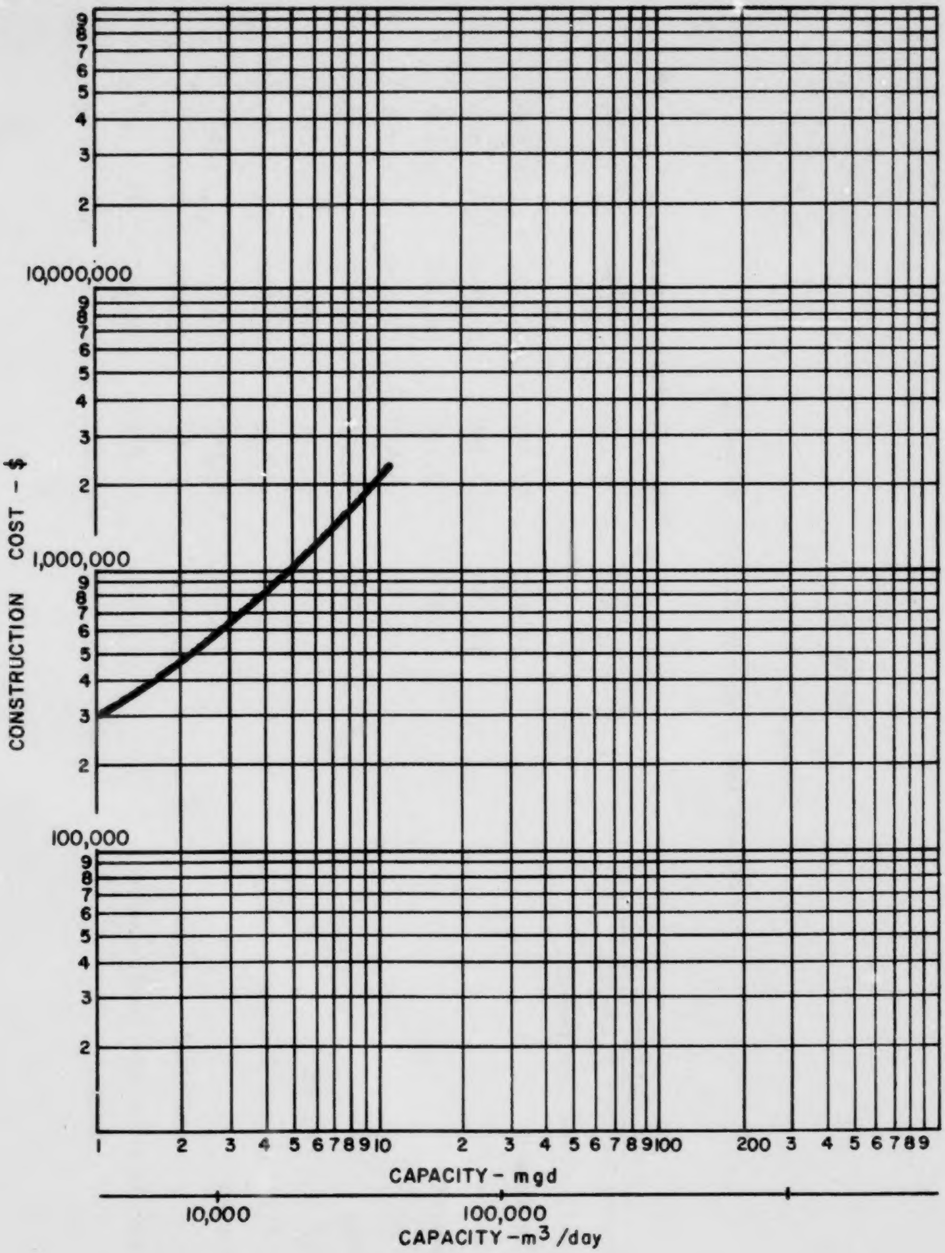


Figure 121. Construction cost for pressure ion exchange nitrate removal.

Table 101

Construction Cost for

Pressure Ion Exchange Nitrate Removal

Cost Category	Plant Capacity (mgd)			
	1.1	3.7	6.1	12.3
Excavation and Sitework	$ 740	$ 1,140	$ 1,470	$ 1,970
Manufactured Equipment				
Equipment	39,960	89,580	137,770	258,230
Media	92,790	313,160	521,940	1,043,880
Concrete	2,410	3,580	4,750	6,320
Steel	3,830	5,680	7,530	9,950
Labor	17,420	33,510	61,460	125,080
Pipe and Valves	14,040	38,780	69,740	139,480
Electrical and Instrumentation	27,700	38,510	60,820	120,210
Housing	21,920	35,660	57,440	79,820
SUBTOTAL	220,810	559,600	922,920	1,784,940
Miscellaneous and Contingency	33,120	83,940	138,440	267,740
TOTAL	253,930	643,540	1,061,360	2,052,680

plants and filter pumping facilities of comparable size. Labor requirements are also included for periodic media addition and replacement of the media every 4 years.

No costs are included for spent brine disposal. Operation and maintenance curves are presented in Figures 122 and 123 and are summarized in Table 102.

ACTIVATED ALUMINA FOR FLUORIDE REMOVAL

Construction Cost

Water supplies with fluoride concentrations of 10 mg/l or greater can be effectively treated by contact with activated alumina. Fluoride reductions to less than 0.5 mg/l are generally achieved by activated alumina contact, with blending being utilized to meet desired fluoride concentrations. Treatment is generally selective for fluoride and arsenic, although small amounts of other anions often are removed. Regeneration of the activated alumina with caustic removes both exchanged fluoride and arsenic.

Facilities were sized based on a fluoride exchange capacity of 0.6 percent by weight, or 0.25 lb of fluoride/ft^3 of activated alumina, and a fluoride reduction from 3 to 0.5 mg/l. Operation was assumed to be at pH 5.5, although higher pH values may be used with a resulting lower exchange capacity. The cost of pH adjustment, if required, is not included and must be added separately. Regeneration facilities were sized on the basis of batch rather than continuous regeneration, because of the significant savings in regeneration chemical cost when batch regeneration is utilized. However, a reduced capacity of the facilities results from the increased regeneration time. Two 1-hr contacts with 0.1 N sodium hydroxide were included for fluoride removal from the alumina, followed by a 1/2-hr contact with 0.05 N sulfuric acid for neutralization of remaining caustic. An activated alumina void volume of 2.28 gal/ft^3 and in-place resin costs of \$13.86/ft^3 were utilized. Feed water was assumed to be sufficiently low in suspended solids so that backwashing was only occasionally necessary, although backwashing facilities are included in the construction cost.

Construction costs were developed for activated alumina ion exchange using the conceptual information presented in Table 103. The contact vessels are fabricated steel with a baked phenolic lining; they are constructed for 100 psi working pressure. The depth of resin was 10 ft, and the contact vessel was designed for 80 percent media expansion during backwash. A gravel layer between underdrains and media was not included.

Regeneration storage facilities were sized for a 30-day requirement. Sodium hydroxide required for regeneration was assumed to be purchased in a solid form for capacities less than 10 mgd, and as a 50 percent solution for larger plants. A caustic dilution tank was included when the 50-percent solution was used. Because of the small requirement for sulfuric acid, a concentrated sulfuric acid storage tank was only included for 70 mgd and larger plants, although a sulfuric acid dilution tank was included in each case. Metering pumps were included for transfer of concentrated caustic and sulfuric acid to the dilution tanks, and pumping facilities were included to pump from the dilution tanks to the exhausted contactor.

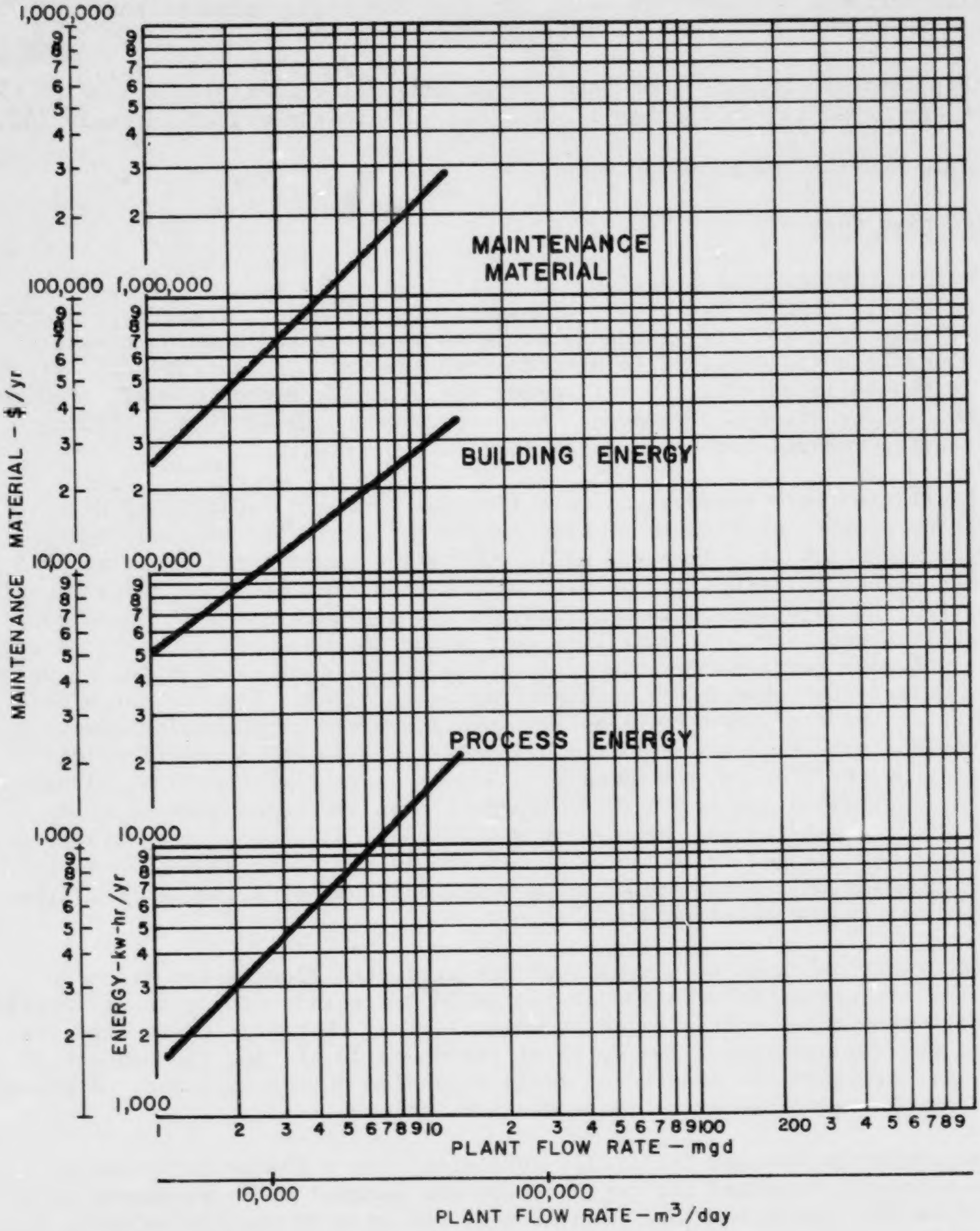


Figure 122. Operation and maintenance requirements for pressure ion exchange nitrate removal - building energy, process energy, and maintenance material.

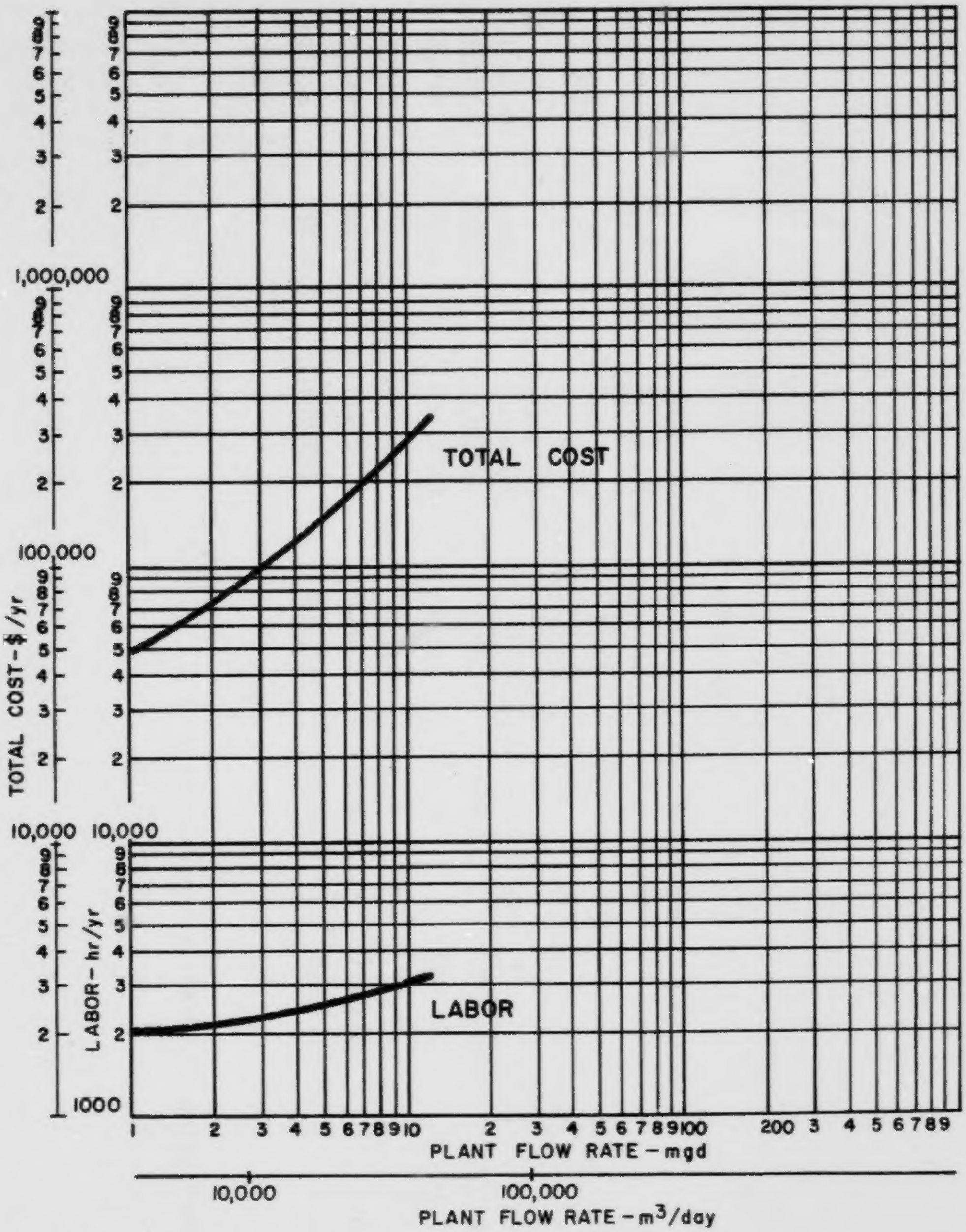


Figure 123. Operation and maintenance requirements for pressure ion exchange nitrate removal - labor and total cost.

Table 102

Operation and Maintenance Summary for Pressure Ion Exchange Nitrate Removal

Plant Capacity (mgd)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1.1	56,090	1,900	57,990	$ 25,770	2,200	$49,510
3.7	126,400	6,380	132,780	85,240	2,500	114,220
6.1	203,150	10,510	213,660	141,830	3,000	178,240
12.3	313,960	21,200	335,160	283,000	3,300	326,050

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 103

Conceptual Design for Activated Alumina for Fluoride Removal

Plant Capacity (mgd)	Number of Contactors	Diameter of Contactors (ft)	Housing (ft^2)
0.7	2	6	252
2.0	2	10	700
6.8	5	12	1,980
27	20	12	7,920
54	40	12	15,840
135	100	12	31,680

All facilities were assumed to be located indoors. Construction costs are presented in Table 104 and in Figure 124.

Operation and Maintenance Cost

Electrical energy costs are for regenerant pumping, occasional backwash pumping, and building heating, ventilation, and lighting. The latter requirements constitute the majority of the energy requirements. Use of an outdoor installation would have a very significant impact on energy requirements. Process energy is extremely small, as it is used only for regenerant pumping. If backwash were required, process energy requirements would increase significantly.

Maintenance material costs are for periodic repair and replacement of components, and they were estimated on the basis of 1 percent of the construction cost. An activated alumina replacement cost was also included in maintenance material, at an annual rate of 10 percent. Regenerant costs are not included in the maintenance material costs.

Labor requirements are principally for regenerant preparation and regeneration of the activated alumina. Labor requirements also include periodic media addition to make up losses and occasional replacement.

Operation and maintenance curves are presented in Figures 125 and 126 and summarized in Table 105.

GRAVITY CARBON CONTACTORS - CONCRETE CONSTRUCTION

Construction Cost

Concrete gravity carbon contactors are essentially identical to gravity filtration structures, and the same conceptual layout was used for both. Costs were developed for carbon bed depths of 5 ft and 8.3 ft, which provide empty bed contact times of 7.5 and 12.5 min, respectively, at an application rate of 5 gpm/ft^2.

Carbon removal from the contactor is accomplished using a series of troughs located at the carbon/support gravel interface. The carbon slurry is then pumped to dewatering and regeneration facilities. Carbon removal troughs and piping were sized to maintain a velocity of 3 ft/second with a carbon slurry of 3 lb carbon/gal. The troughs, each of which have plug style valves, are manifolded into a spent carbon transfer system. Regenerated carbon is transported through a similar piping system.

The costs presented are for a complete carbon contacting facility, including the contactor structure, cylinder-operated butterfly valves, liquid and carbon handling piping with headers in a pipe gallery, flow measurement and other instrumentation, master operations control panel and building. Housing requirements were developed assuming that the entire carbon contactor structure is enclosed.

Table 104

Construction Cost for

Activated Alumina for Fluoride Removal

	Plant Capacity (mgd)					
Cost Category	0.7	2.0	6.8	27	54	135
Manufactured Equipment						
Equipment	$26,760	$ 44,580	$ 138,330	$ 522,210	$ 1,031,270	$2,564,560
Activated Alumina	8,300	14,770	83,080	332,310	664,610	1,661,530
Labor	10,280	13,490	48,010	192,020	384,060	1,282,370
Pipe and Valves	16,260	19,320	69,030	273,210	542,650	1,368,060
Electrical and Instrumentation	10,050	11,360	22,300	60,300	119,030	284,750
Housing	6,960	27,630	62,120	210,980	374,840	744,320
SUBTOTAL	78,610	131,150	422,870	1,591,030	3,116,460	7,905,590
Miscellaneous and Contingency	11,790	19,670	63,430	238,650	467,470	1,185,840
TOTAL	90,400	150,820	486,300	1,829,680	3,583,930	9,091,430

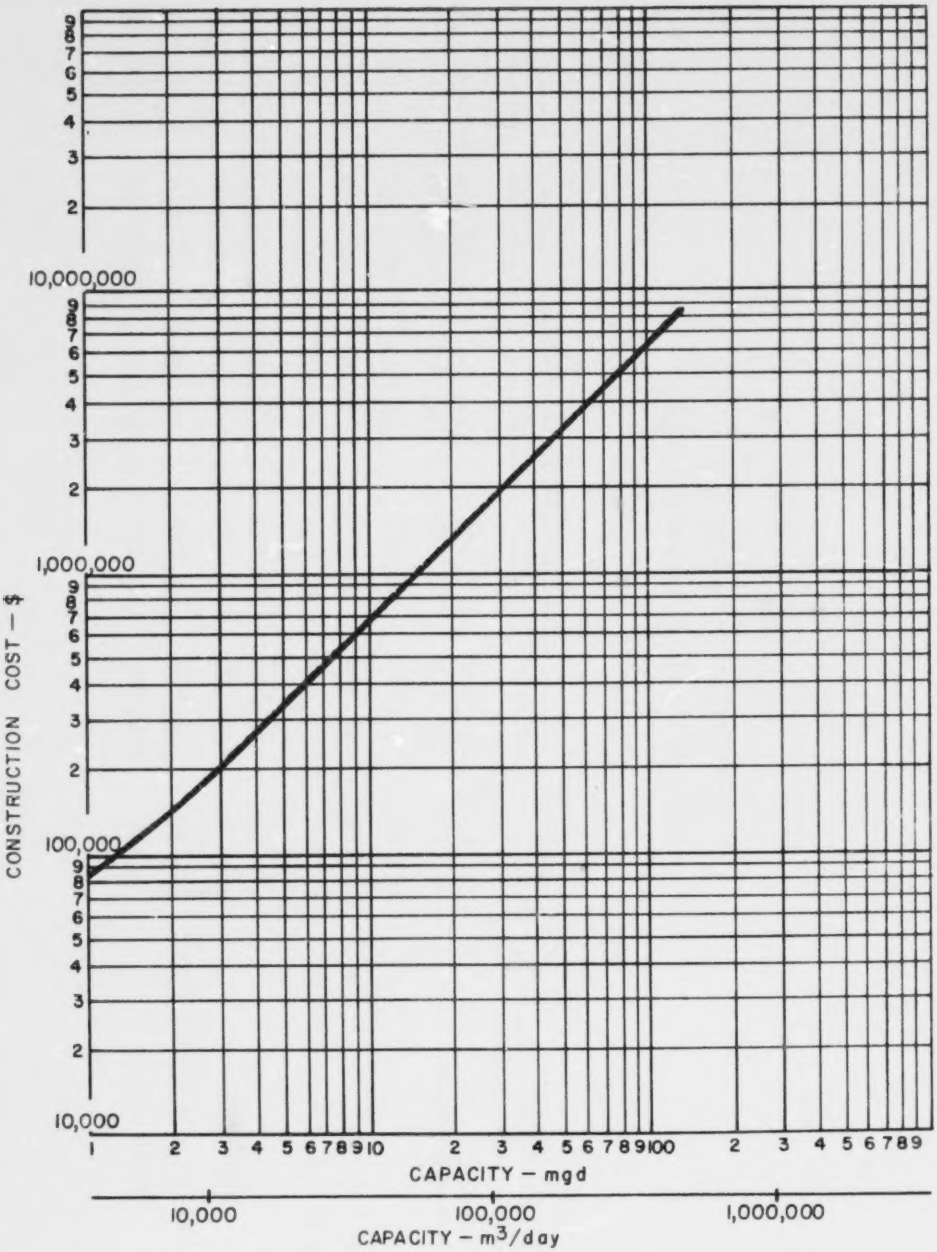


Figure 124. Construction cost for activated alumina fluoride removal.

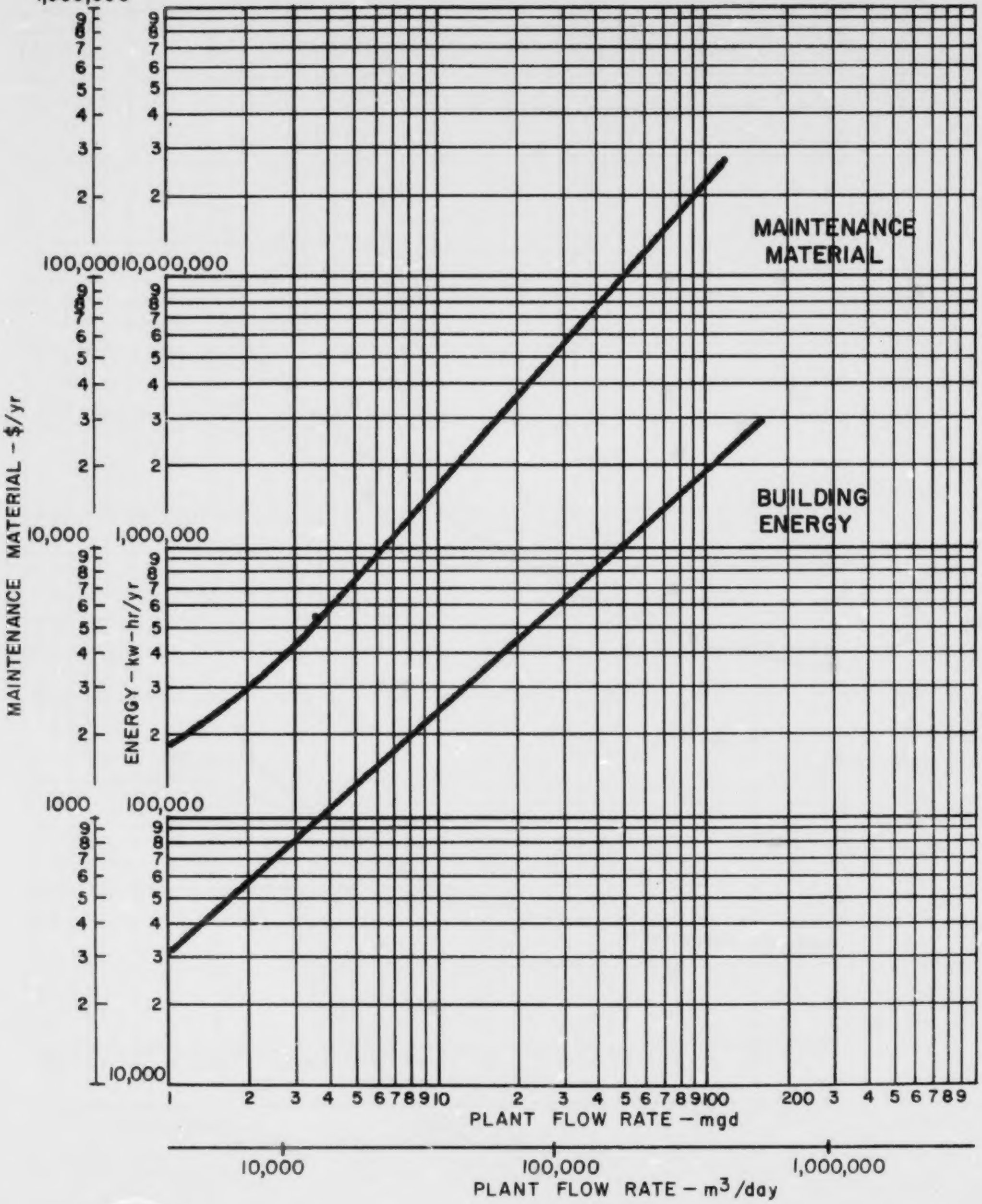


Figure 125. Operation and maintenance requirements for activated alumina for fluoride removal - building energy and maintenance material.

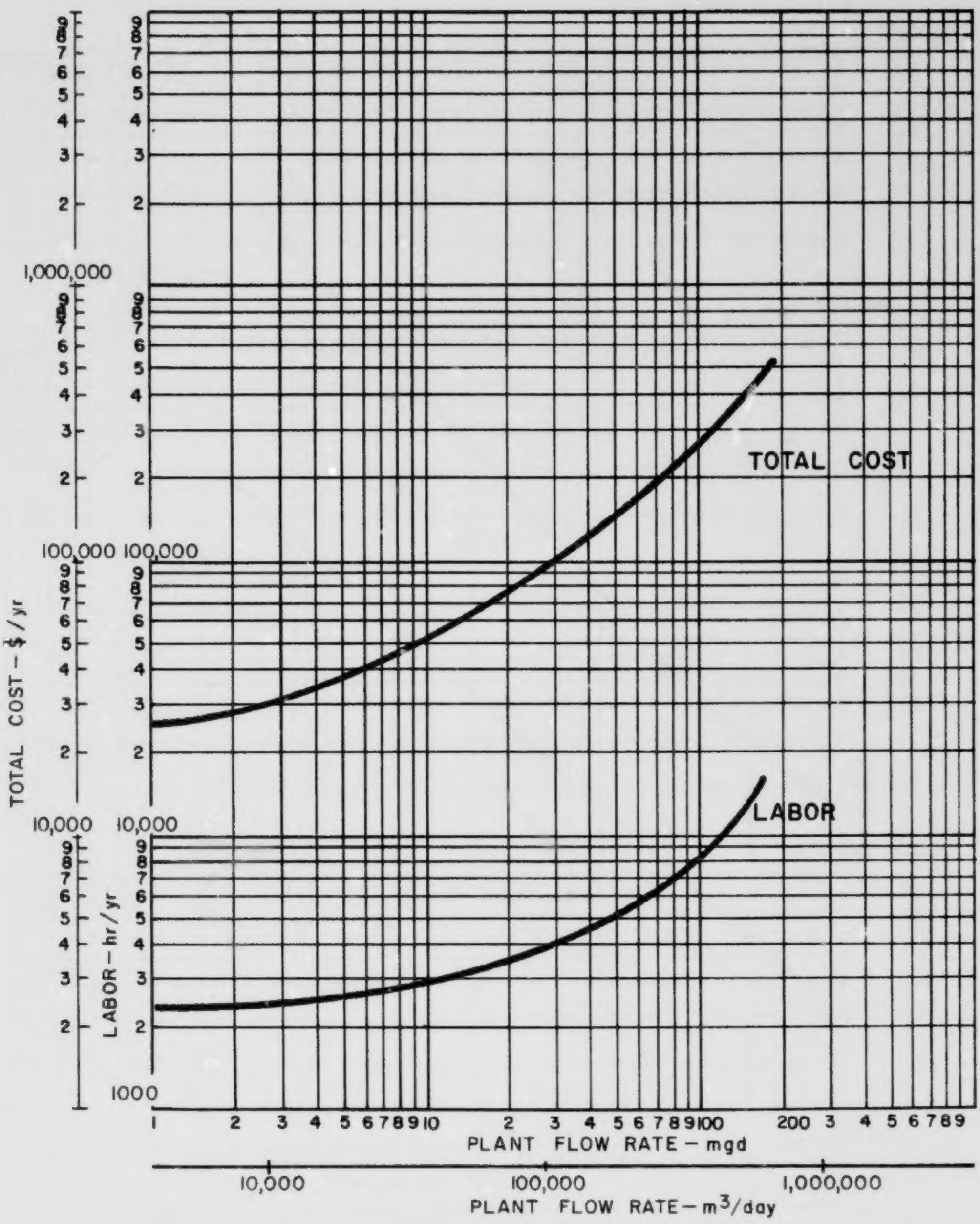


Figure 126. Operation and maintenance requirements for activated alumina for fluoride removal - labor and total cost.

Table 105
Operation and Maintenance Summary for Activated Alumina for Fluoride Removal

Plant Capacity (mgd)	Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
0.7	17,640	40	17,680	$ 1,900	2,400	$ 26,430
2.0	49,000	100	49,100	3,250	2,580	30,520
6.8	138,600	350	138,950	15,000	2,940	48,570
27	554,400	1,410	555,810	59,500	4,490	121,070
54	1,108,800	2,820	1,111,620	118,800	7,560	227,750
135	2,217,600	7,050	2,224,650	297,930	17,580	540,470

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Not included in the cost estimate for the carbon contactor are backwash pumping, the initial activated carbon charge, spent or regenerated activated carbon handling outside of the contactor pipe gallery, and carbon regeneration and preparation facilities. Separate curves are presented for these costs. In developing construction costs, it was assumed that all carbon in a contactor would be removed and replaced with regenerated carbon in a single operation. This handling method requires that regeneration facilities be designed to store both spent and regenerated carbon in quantities equal to the amount in one contactor.

Estimated construction costs are presented in Tables 106 and 107 and in Figure 127.

Operation and Maintenance Cost

Building energy requirements are for building heating, ventilation, and lighting. Process energy is required for backwash pumping and carbon slurry pumping during carbon removal and replacement. The backwash frequency was assumed to be once/day for 10 min at 12 gpm/ft^2. For carbon removal, a regeneration frequency of every 2 months and a slurry concentration of 3 lb of carbon/gal of water were utilized. Process energy requirements are virtually identical for the two different carbon bed depths.

Maintenance material costs include the cost of general supplies, backwash and carbon transport pump maintenance, instrumentation repair, and other miscellaneous items. The cost for replacement of carbon lost during contactor operation and carbon regeneration is not included in the maintenance material costs.

Labor costs include the cost of operating the contactors, the backwash pumps, and the carbon slurry pumps, as well as the cost of instrument and equipment repairs and supervision.

Figures 128 and 129 present the operation and maintenance requirements, and Table 108 summarizes these requirements.

GRAVITY CARBON CONTACTORS - STEEL CONSTRUCTION

Construction Cost

For carbon treatment facilities requiring in excess of about 30,000 ft^3 of carbon contact volume, the use of large-diameter, field-erected, steel gravity contactors may offer an economic advantage over smaller diameter, factory-built, pressure carbon columns. Costs were developed for 20 ft and 30 ft-diameter steel, gravity contactors, using the conceptual design information in Table 109. A carbon bed depth of 20 ft, with an overall vessel height of 35 ft, was used in the cost analysis. The units are designed for down-flow operation, and the system hydraulics were sized using an application rate of 5 gpm/ft^2, which provides a 30 min empty bed contact time.

Table 106

Construction Cost for Concrete Gravity Carbon Contactors

7.5 min Empty Bed Contact Time and 5 ft Bed Depth

	Total Contactor Volume (ft^3) and Area (ft^2)					
Cost Category	700 ft^3 140 ft^2	3,500 ft^3 700 ft^2	7,000 ft^3 1,400 ft^2	35,000 ft^3 7,000 ft^2	70,000 ft^3 14,000 ft^2	140,000 ft^3 28,000 ft^2
Excavation & Sitework	$ 1,660	$ 3,050	$ 4,660	$ 13,670	$ 21,600	$ 36,630
Manufactured Equipment	29,000	62,660	86,130	335,690	582,300	1,080,360
Concrete	12,330	24,880	38,330	87,850	142,410	253,520
Steel	10,630	18,360	27,710	67,650	113,300	193,160
Labor	37,330	81,410	138,800	327,870	468,260	920,890
Pipe and Valves	33,570	108,700	206,130	597,380	863,970	1,463,150
Electrical & Instrumentation	14,730	42,250	42,250	109,050	185,720	291,840
Housing	17,400	40,480	70,590	291,940	514,330	968,520
SUBTOTAL	156,650	381,790	614,600	1,831,100	2,891,890	5,208,070
Miscellaneous & Contingency	23,500	57,270	92,190	274,670	433,780	781,210
TOTAL	180,150	439,060	706,790	2,105,770	3,325,670	5,989,280
Volume/Single Contactor	350 ft^3	875 ft^3	1,750 ft^3	3,500 ft^3	5,000 ft^3	6,360 ft^3
COST/SINGLE Contactor	$90,070	$109,770	$176,700	$210,580	$237,550	$290,460

Table 107

Construction Cost for Concrete Gravity Carbon Contactors

12.5 Empty Bed Contact Time and 8.3 ft Bed Depth

Cost Category	Total Contactor Volume (ft^3) and Area (ft^2)					
	1,160 ft^3 140 ft^2	5,810 ft^3 700 ft^2	11,620 ft^3 1,400 ft^2	58,100 ft^3 7,000 ft^2	116,200 ft^3 14,000 ft^2	232,400 ft^3 28,000 ft^2
Excavation and Sitework	$ 2,220	$ 4,080	$ 6,210	$ 18,240	$ 28,800	$ 48,770
Manufactured Equipment	29,000	62,660	86,130	335,690	582,300	1,080,630
Concrete	15,010	30,300	51,180	111,090	180,500	308,640
Steel	12,940	20,690	38,800	82,360	137,940	235,150
Labor	45,450	99,170	168,990	399,150	570,050	1,159,990
Pipe and Valves	33,570	108,700	206,130	597,380	863,970	1,463,150
Electrical and Instrumentation	14,730	42,250	42,250	109,050	185,720	291,840
Housing	17,400	40,480	70,590	291,940	514,330	968,520
SUBTOTAL	170,320	408,330	670,280	1,944,900	3,063,610	5,556,690
Miscellaneous and Contingency	25,550	61,250	100,540	291,740	459,540	833,500
TOTAL	195,870	469,580	770,820	2,236,640	3,523,150	6,390,190
Volume/Single Contactor	580 ft^3	1,450 ft^3	2,905 ft^3	5,810 ft^3	8,300 ft^3	10,560 ft^3
COST/SINGLE Contactor	$97,940	$117,400	$192,710	$223,660	$251,650	$290,460

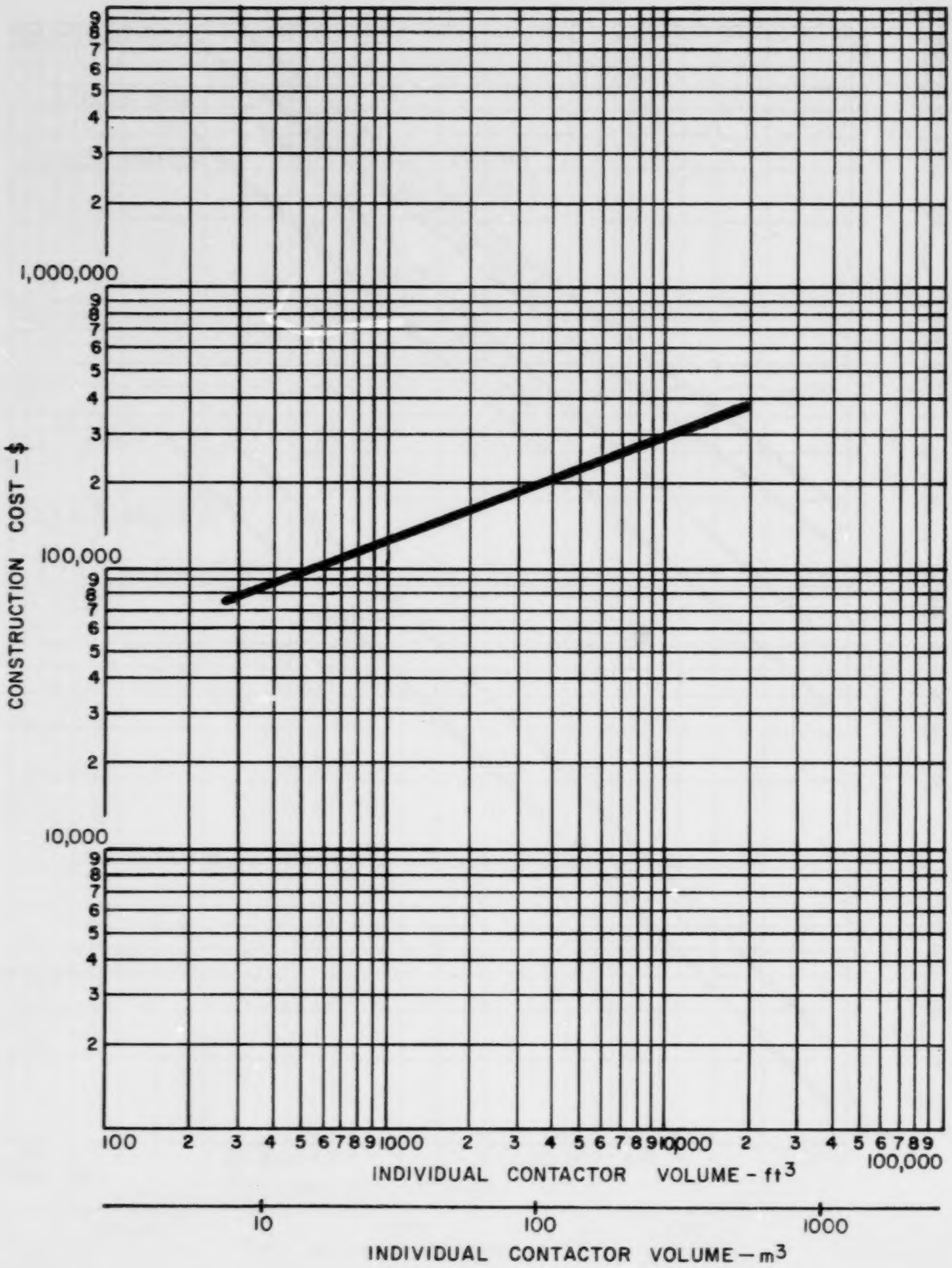


Figure 127. Construction cost for gravity carbon contactors - concrete construction.

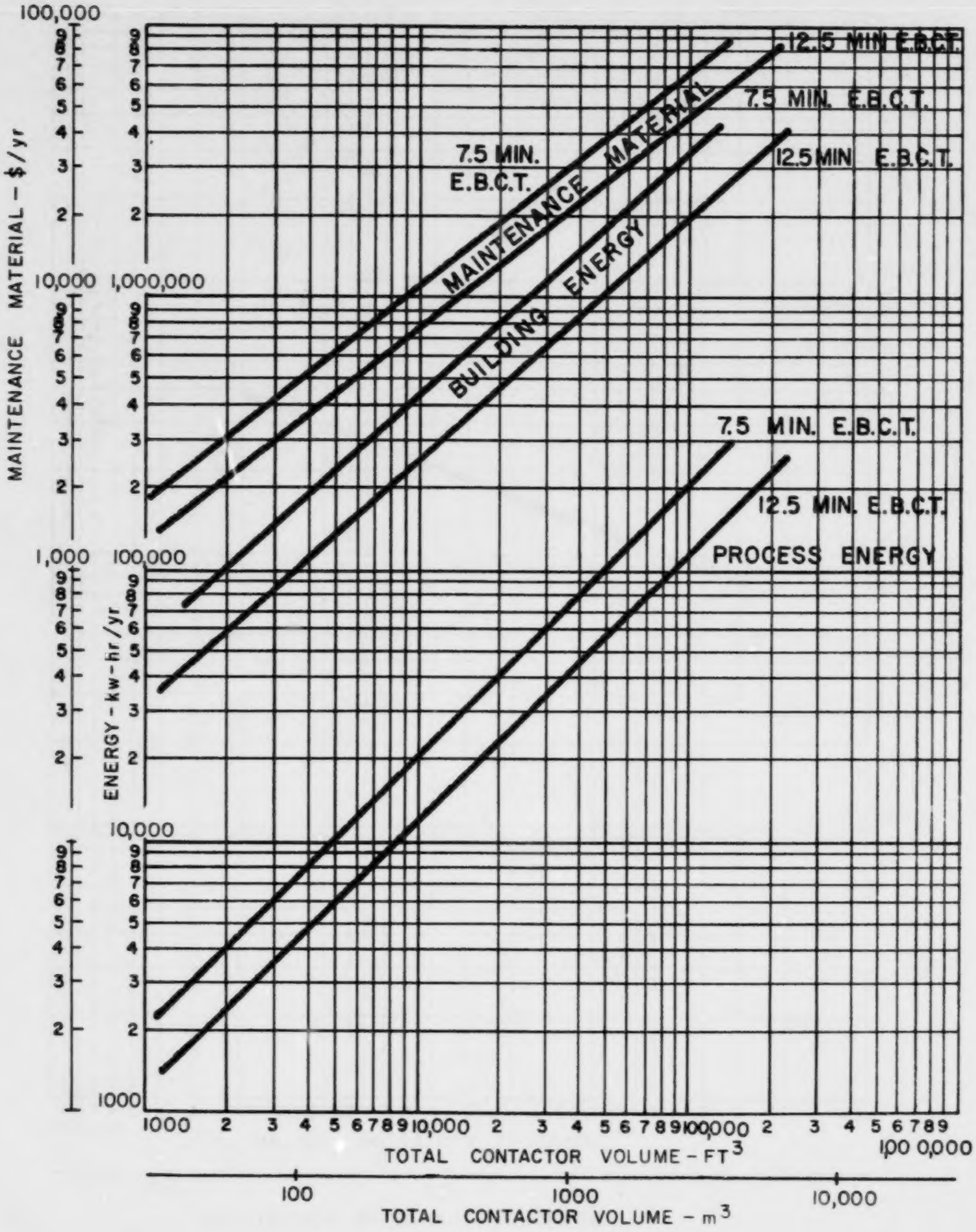


Figure 128. Operation and maintenance requirements for concrete gravity carbon contactors - building energy, process energy, and maintenance material needed for 7.5 and 12.5 min empty bed contact times.

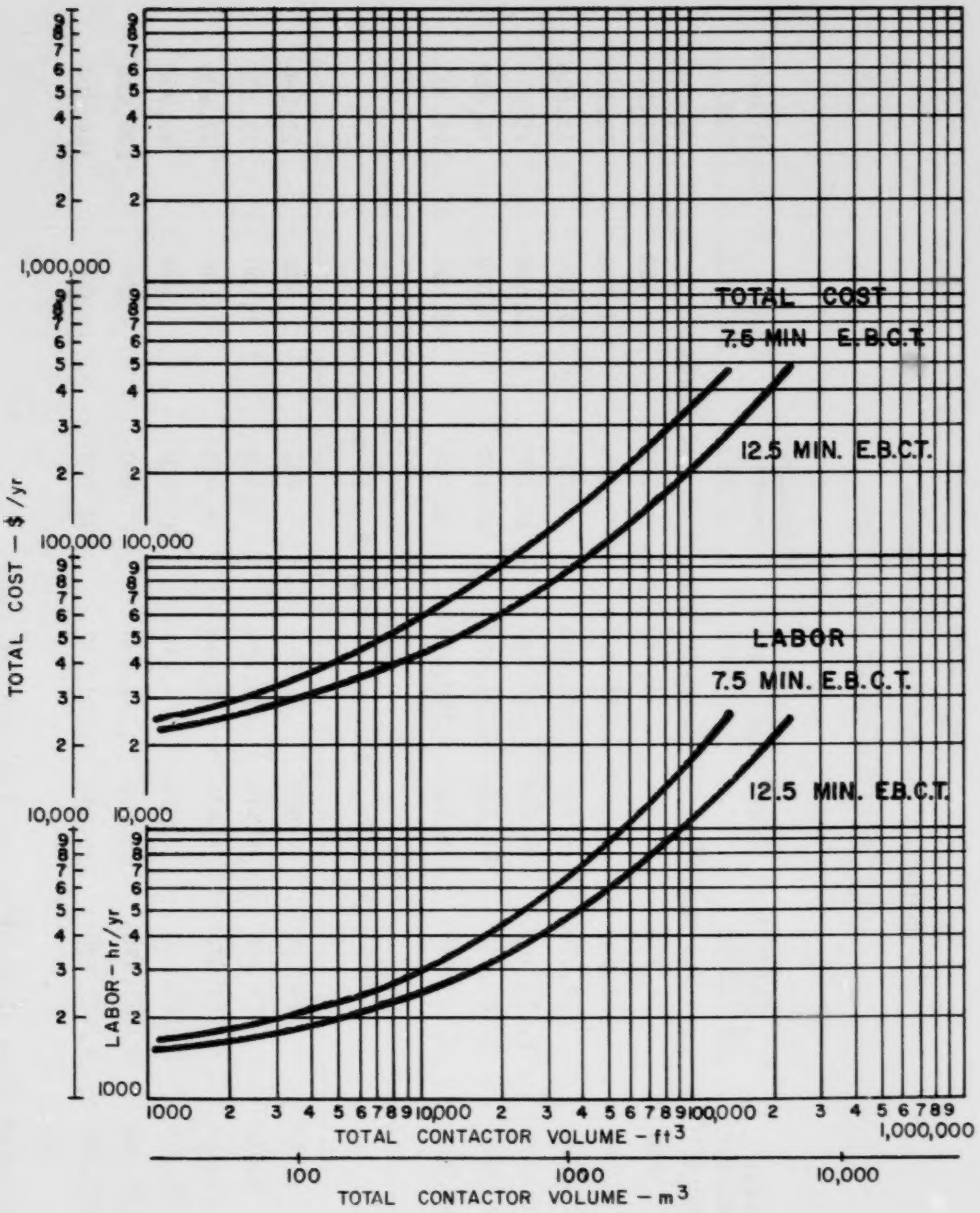


Figure 129. Operation and maintenance requirements for concrete gravity carbon contactors - labor and total cost needed for 7.5 and 12.5 min empty bed contact time.

Table 108

Operation and Maintenance Summary for Gravity Carbon Contactors

Total Contactor Volume (ft^3)	Electrical Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
	7.5 min empty bed contact time, 5 ft bed depth					
700	44,120	690	44,810	800	900	11,140
3,500	151,850	3,410	155,260	2,510	1,500	22,170
7,000	279,070	6,820	285,890	4,020	2,100	33,600
35,000	1,190,160	34,080	1,224,240	13,200	4,600	95,930
70,000	2,165,890	68,150	2,234,040	21,600	9,000	178,620
140,000	4,123,490	136,540	4,260,030	36,700	18,000	344,500
	12.5 min empty bed contact time, 8.3 ft bed depth					
1,160	44,120	690	44,810	800	900	11,140
5,810	151,850	3,410	155,260	2,510	1,500	22,170
11,620	279,070	6,820	285,890	4,020	2,100	33,600
58,200	1,190,160	34,080	1,224,240	13,200	4,600	95,930
116,200	2,165,890	68,150	2,234,040	21,600	9,000	178,620
232,400	4,123,490	136,540	4,260,030	36,700	18,000	344,500

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

Table 109

Conceptual Design for Steel Gravity Carbon Contactors

20-ft Carbon Bed Depth

Plant Flow (mgd)	Total Contactor Bed Area (ft^2)		Number of Contactors		Total Carbon Volume (ft^3)		Plant Area Requirements (ft^2)	
	20' diam.	30' diam.	20' diam.	30' diam.	20' diam.	30' diam.	20' diam.	30' diam.
10	1,570	--	5	--	31,400	--	6,500	--
50	7,850	7,065	25	10	157,000	141,300	33,000	26,000
100	15,700	14,130	50	20	314,000	282,600	66,000	50,000
200	31,400	28,260	100	40	628,000	565,200	126,000	95,000

The vessels are constructed of factory-formed steel plates erected at the jobsite. Units are provided with a nozzle-style underdrain, eliminating the need for a supporting gravel layer. Carbon is removed from each contactor as required for regeneration through multiple carbon drawoff pipes in the underdrain support plate. Regenerated carbon is returned through a piping system to the top of each contactor.

The costs presented are for a complete carbon contacting facility, including vessels, face and interconnecting piping, access walkways, cylinder-operated butterfly valves on all hydraulic piping and manually operated ball or knife-type valves on carbon handling system, flow control and other instrumentation, master operations control panel, and a building to house the contactors completely.

Not included in the construction costs are carbon contactor supply pumping, surface wash and backwash pumping, the initial activated carbon charge, spent or regenerated carbon handling facilities (exclusive of piping within the contactor building), or carbon regeneration or preparation facilities. Curves for estimating the costs for these facilities are presented separately.

Estimated construction costs for gravity carbon contactors are presented in Tables 110 and 111 for 20 ft and 30 ft diameter units, respectively. Figures 130 shows the construction cost curve for gravity carbon contactors.

Operation and Maintenance Cost

Building energy requirements are for building heating, ventilation, and lighting. Process energy is required for the backwash pumping and carbon slurry pumping during carbon removal and replacement. The backwash frequency was assumed to be once/day for 10 min at 12 gpm/ft^2. For carbon removal, a regeneration frequency of every 2 months and a slurry concentration of 3 lb of carbon/gal of water were utilized.

Maintenance material costs include the cost of general supplies, backwash and carbon transport pump maintenance, instrumentation repair, and other miscellaneous items. The cost for replacement of carbon lost during contactor operation and carbon regeneration is not included in the maintenance material costs. A separate curve is provided for makeup carbon, and this cost must be added separately.

Labor costs include the cost of operating the contactors, the backwash pumps, and the carbon slurry pumps, as well as the cost of instrument and equipment repairs and supervision.

Figures 131 and 132 present the operation and maintenance requirements, and Table 112 summarizes these requirements.

Table 110

Construction Cost for Steel Gravity Carbon Contactors

20-ft Diameter Tanks

Cost Category	Total Contactor Volume			
	31,400 ft^3	157,000 ft^3	314,000 ft^3	628,000 ft^3
Excavation and Sitework	$ 2,050	$ 6,560	$11,600	$21,760
Manufactured Equipment	340,970	1,619,750	3,170,980	6,137,800
Concrete	7,650	27,470	47,290	91,580
Steel	3,810	14,040	24,370	45,690
Labor	66,220	314,270	584,390	1,075,550
Pipe and Valves	140,730	675,500	1,437,110	2,644,620
Electrical and Instrumentation	50,460	207,800	406,820	787,250
Housing	169,000	792,000	1,584,000	3,024,000
SUBTOTAL	780,890	3,657,390	7,266,560	13,828,250
Miscellaneous and Contingency	117,130	548,610	1,089,980	2,074,240
TOTAL	898,020	4,206,000	8,356,540	15,902,490
VOLUME/SINGLE CONTACTOR	6,280 ft^3	6,280 ft^3	6,280 ft^3	6,280 ft^3
COST/SINGLE CONTACTOR	$179,600	$168,240	$167,130	$159,020

Table 111

Construction Cost for Steel Gravity Carbon Contactors

30-ft Diameter Tanks

Cost Category	Total Contactor Volume		
	$141,300\ ft^3$	$282,600\ ft^3$	$565,200\ ft^3$
Excavation & Sitework	$ 7,150	$ 13,140	$ 25,020
Manufactured Equipment	1,327,160	2,595,980	5,139,970
Concrete	29,680	56,180	111,290
Steel	15,230	28,690	55,180
Labor	263,820	488,740	942,800
Pipe and Valves	565,490	1,092,710	2,111,020
Electrical & Instrumentation	170,640	332,910	659,530
Housing	624,000	1,200,000	2,280,000
SUBTOTAL	3,003,170	5,808,350	11,324,810
Miscellaneous & Contingency	450,480	871,250	1,698,720
TOTAL	3,453,650	6,679,600	13,023,530
VOLUME/SINGLE CONTACTOR	$14,140\ ft^3$	$14,140\ ft^3$	$14,140\ ft^3$
COST/SINGLE CONTACTOR	$ 345,370	$ 333,980	$ 325,590

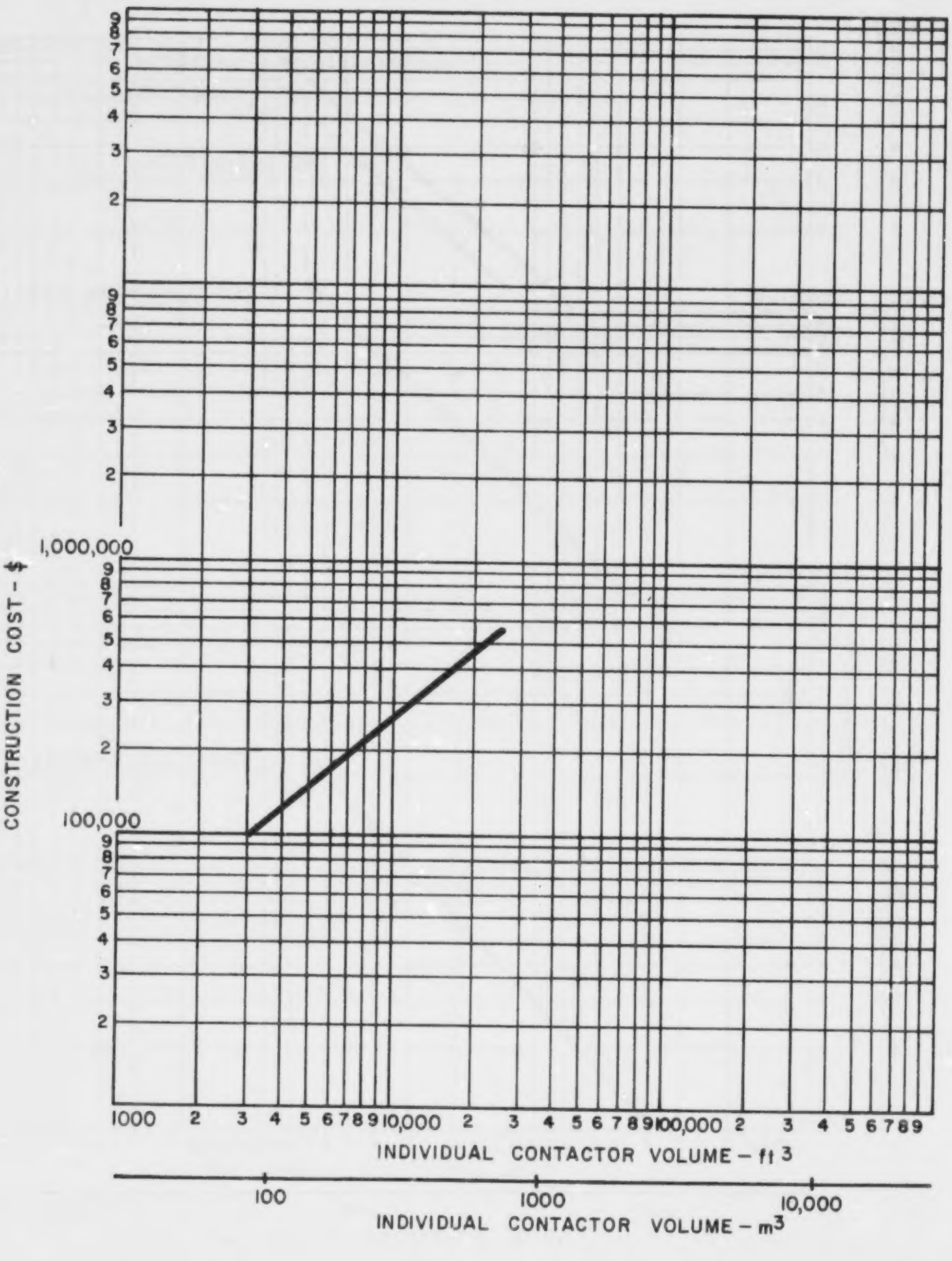


Figure 130. Construction cost for steel gravity carbon contactors.

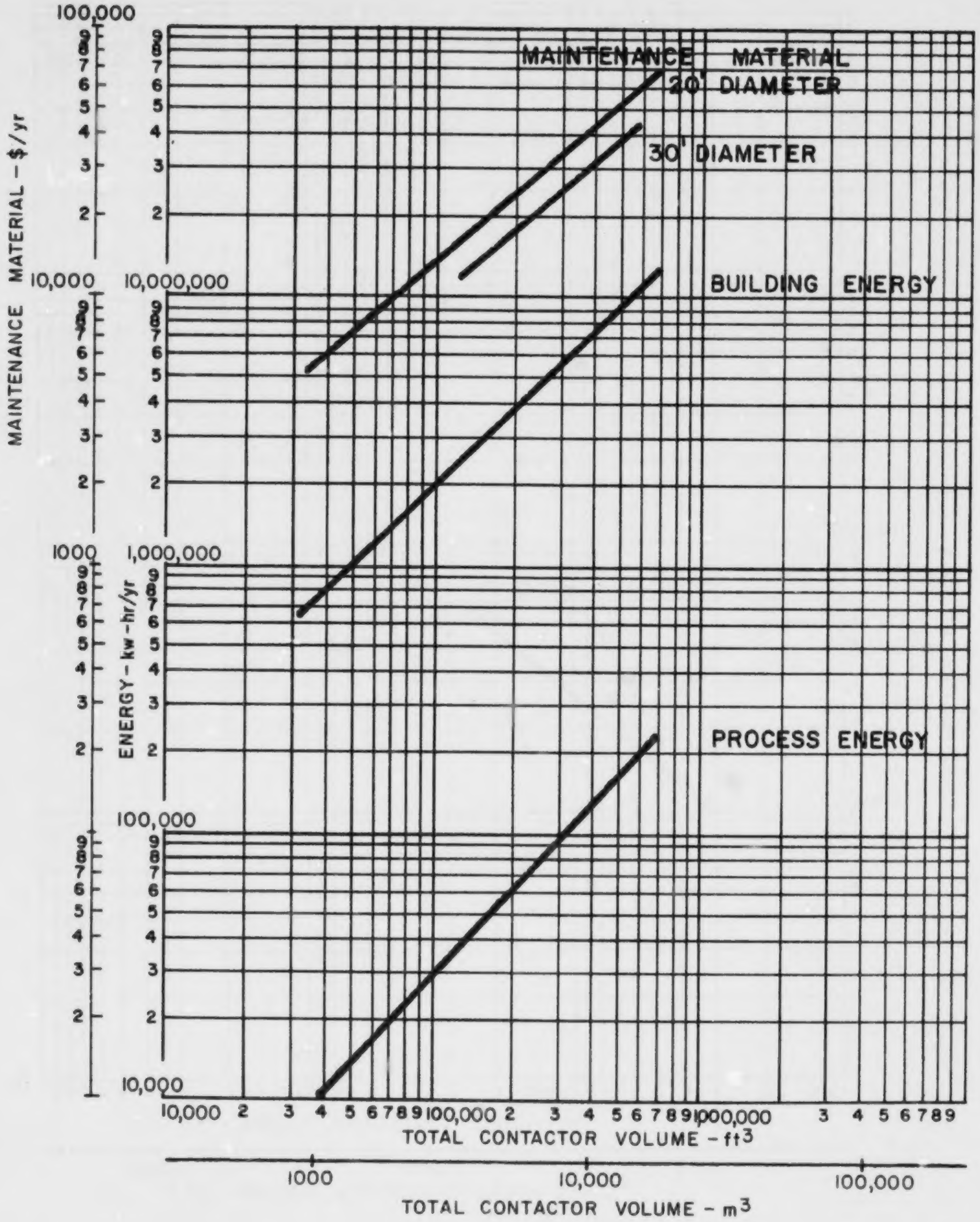


Figure 131. Operation and maintenance requirements for steel gravity carbon contactors - building energy, process energy, and maintenance material.

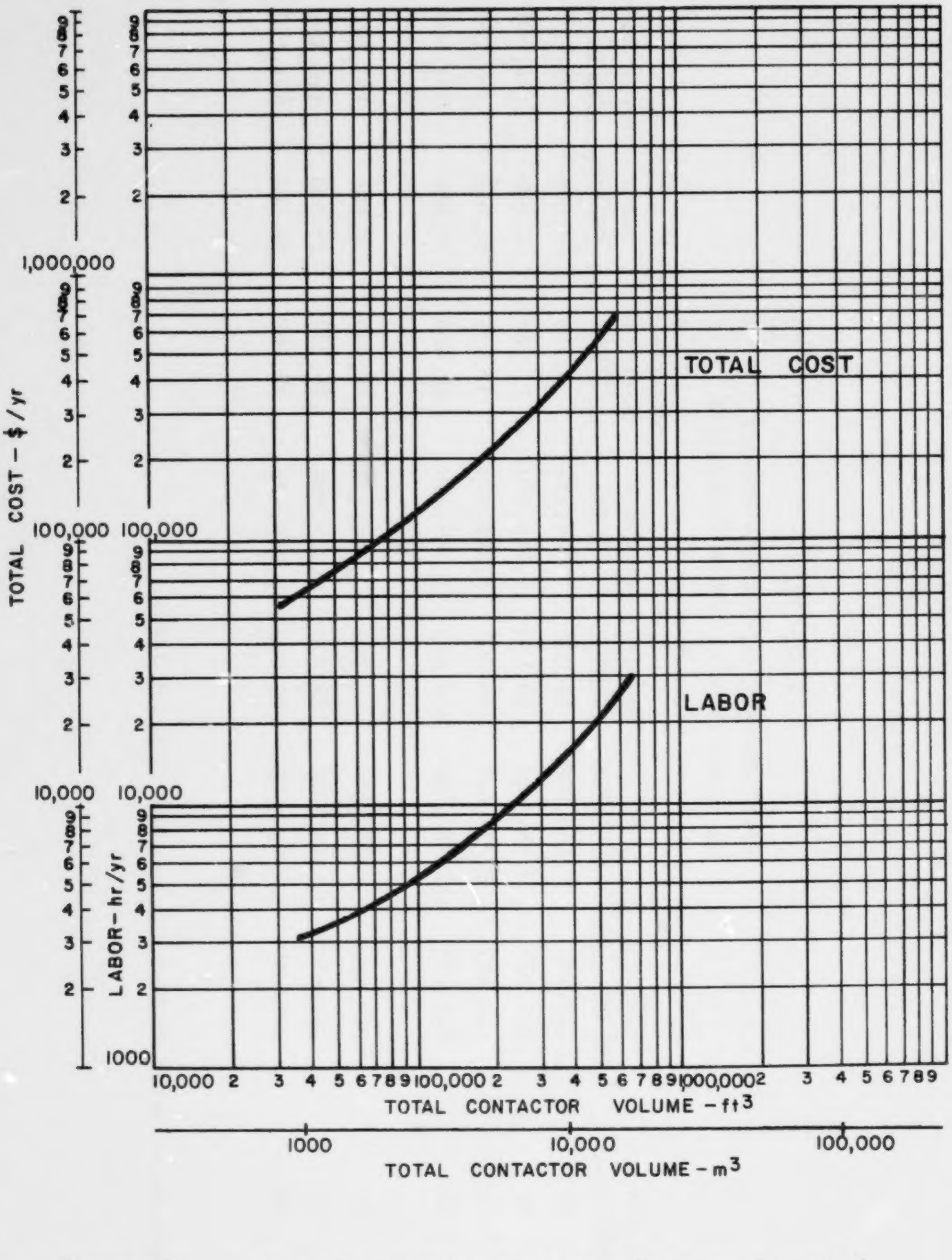


Figure 132. Operation and maintenance requirements for steel gravity carbon contactors - labor and total cost.

Table 112

Operation and Maintenance Summary
for Steel Gravity Carbon Contactors

Contactor Diameter (ft)	Carbon Volume (ft^3)	Electrical Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
20	31,400	666,900	12,030	678,930	5,350	3,000	55,720
20	157,100	3,385,800	60,170	3,445,970	21,380	7,000	194,760
20	314,000	6,771,600	120,340	6,891,940	37,420	14,000	384,180
20	628,000	12,927,600	240,680	13,168,280	69,490	27,000	734,540
30	141,300	2,668,000	54,150	2,722,150	16,040	6,800	165,700
30	282,600	5,130,000	108,300	5,238,300	26,730	13,500	318,880
30	565,200	9,750,000	216,600	9,966,600	42,760	26,000	601,760

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

PRESSURE CARBON CONTACTORS

Construction Cost

Construction costs were developed for pressure granular activated carbon contactors constructed of shop-fabricated steel tankage. Bed depths of 5, 10, and 20 ft were used, which provide empty bed contact times of 7.5, 15, and 30 min at a hydraulic loading rate of 5 gpm/ft^2. Conceptual design information is shown in Table 113, and a typical layout for pressure carbon contactors is shown in Figure 133. The practical upper limit for pressure carbon contactors is generally in the range of 20 to 25 mgd.

The cost for the steel contactors was based on pressurized downflow operation using cylindrical ASME code pressure vessels with a design working pressure of 50 psi. Vessels used were either 10 ft or 12 ft in diameter by 14, 23, and 33 ft in overall height. Carbon contactors are furnished with a nozzle-style underdrain and are designed for rapid removal of spent carbon and recharge of virgin carbon.

The costs presented are for a complete carbon contacting facility, including vessels, cylinder-operated butterfly valves, liquid and carbon handling face piping with headers within the carbon contactor building, flow measurement and other instrumentation, master operations control panel, and building. Not included in the cost estimate are carbon contactor supply and backwash pumping, initial activated carbon charge, spent or regenerated activated carbon handling, and carbon regeneration and preparation facilities. Separate curves are provided for these facilities.

Housing requirements were developed assuming that the carbon columns are totally enclosed. Additional space for pipe galleries and operating and maintenance service areas are also included in the area requirements.

Estimated construction costs are presented in Tables 114, 115, 116, and in Figures 134.

Operation and Maintenance Cost

Electrical energy requirements were computed assuming that the carbon contactors serve as both filters and carbon contactors; thus periodic backwashing is required. Backwash pumping requirements are based on one backwash/day for 10 min duration at a rate of 12 gpm/ft^2. Energy requirements are for backwash pumping, for pumping of spent carbon to regeneration facilities, and for return of regenerated carbon. Carbon was assumed to be removed and replaced every 2 months. Energy for supply pumping to contactors is not included. Building energy requirements are for heating, lighting, ventilating, instrumentation, and other general building purposes. It was assumed that the contactors were completely housed.

Maintenance material costs reflect estimated annual requirements for general supplies, pumps, instrumentation repair, valve replacement or repair, and other miscellaneous work items. Costs for replacement of carbon lost during contactor operation and carbon regeneration are not

Table 113

Conceptual Design for Pressure Carbon Contactors

Plant Flow (mgd)	Number of Contactors	Diameter of Contactors (ft)	Total Contactor* Area (ft^2)	Total Carbon Volume+ (ft^3 @ detention times) 7.5 min	15 min	30 min	Plant Area‡ Requirements (ft^2)
1	2	10	157	780	1,570	3,140	1,750
10	12	12	13,57	6,790	13,570	27,140	4,800
50	60	12	6,786	33,930	67,860	135,720	21,000

*Carbon contactors sized for 5 gpm/ft^2 application rate.

+Volumes determined at bed depth of 5, 10, and 20 ft.

‡Assumes that carbon contactors are totally enclosed.

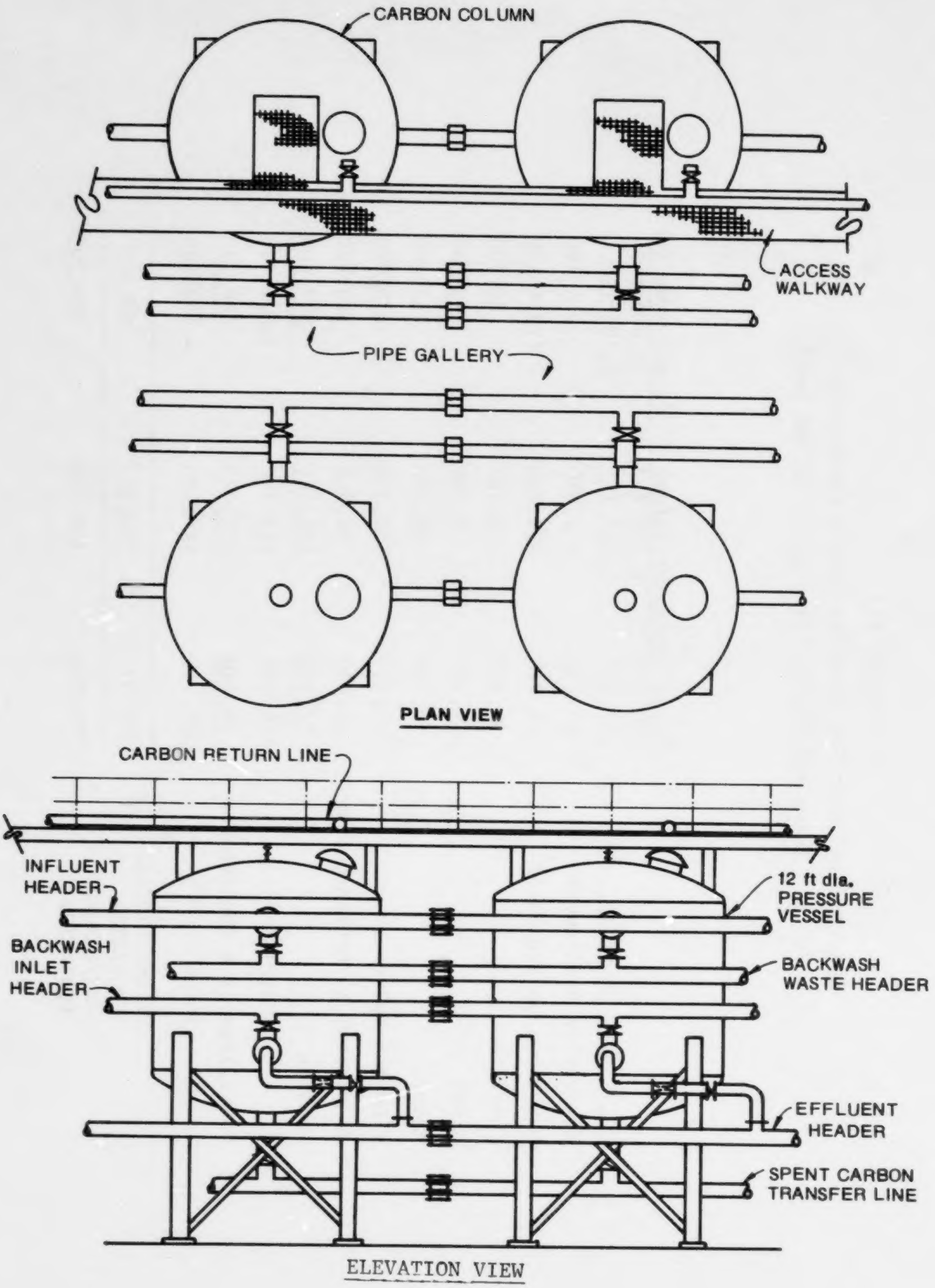

CARBON COLUMN
ACCESS WALKWAY
PIPE GALLERY
PLAN VIEW
CARBON RETURN LINE
INFLUENT HEADER
12 ft dia. PRESSURE VESSEL
BACKWASH INLET HEADER
BACKWASH WASTE HEADER
EFFLUENT HEADER
SPENT CARBON TRANSFER LINE
ELEVATION VIEW

Figure 133. Typical activated carbon column installation.

Table 114

Construction Cost for Pressure Carbon Contactors - 7.5 min Empty Bed Contact Time and 5 ft Bed Depth

Cost Category	Total Contactor Volume (ft^3) and Area (ft^2)		
	780 ft^3, 157 ft^2	6,790 ft^3, 1,357 ft^2	33,930 ft^3, 6,786 ft^2
Excavation & Sitework	$ 530	$ 1,440	$ 6,180
Manufactured Equipment	49,010	409,290	1,944,170
Concrete	2,190	5,650	24,730
Steel	1,130	2,830	12,360
Labor	8,500	55,200	262,400
Pipe and Valves	15,250	135,310	679,880
Electrical & Instrumentation	15,630	82,910	429,660
Housing	32,550	125,160	512,400
SUBTOTAL	124,790	817,790	3,871,780
Miscellaneous & Contingency	18,720	122,670	580,770
TOTAL	143,510	940,460	4,452,550
VOLUME/SINGLE CONTACTOR	390 ft^3	565 ft^3	565 ft^3
COST/SINGLE CONTACTOR	$71,760	$78,370	$74,210

Table 115

Construction Cost for Pressure Carbon Contactors - 15-min Empty Bed Contact Time and 10-ft Bed Depth

	Total Contactor Volume (ft^3) and Area (ft^2)		
Cost Category	1,570 ft^3, 157 ft^2	13,570 ft^3, 1,357 ft^2	67,860 ft^3, 6,786 ft^2
Excavation & Sitework	$ 530	$ 1,490	$ 6,180
Manufactured Equipment	55,460	452,720	2,161,360
Concrete	2,190	5,650	24,730
Steel	1,130	2,830	12,360
Labor	8,990	58,570	280,050
Pipe & Valves	16,780	147,490	728,540
Electrical & Instrumentation	15,680	82,910	429,660
Housing	41,850	163,000	700,290
SUBTOTAL	142,610	914,660	4,343,170
Miscellaneous & Contingency	21,390	137,200	651,480
TOTAL	164,000	1,051,860	4,994,650
VOLUME/SINGLE CONTACTOR	785 ft^3	1,130 ft^3	1,130 ft^3
COST/SINGLE CONTACTOR	$82,000	$87,660	$83,240

Table 116

Construction Cost for Pressure Carbon Contactors - 30-min Empty Bed Contact Time and 20-ft Bed Depth

Cost Category	Total Contactor Volume (ft^3) and Area (ft^2)		
	3,140 ft^3, 157 ft^2	27,140 ft^3, 1,357 ft^2	135,720 ft^3, 6,786 ft^2
Excavation & Sitework	$ 530	$ 1,400	$ 6,180
Manufactured Equipment	77,300	749,560	3,560,370
Concrete	2,630	6,780	29,680
Steel	1,240	3,110	13,600
Labor	10,340	67,370	322,060
Pipe & Valves	18,500	221,730	1,120,350
Electrical & Instrumentation	16,420	87,100	451,200
Housing	79,050	303,420	1,332,250
SUBTOTAL	206,010	1,440,460	6,835,690
Miscellaneous & Contingency	30,900	216,070	1,025,350
TOTAL	236,910	1,656,530	7,861,040
VOLUME/SINGLE CONTACTOR	1,570 ft^2	2,250 ft^2	2,250 ft^2
COST/SINGLE CONTACTOR	$ 171,520	$ 154,140	$ 143,960

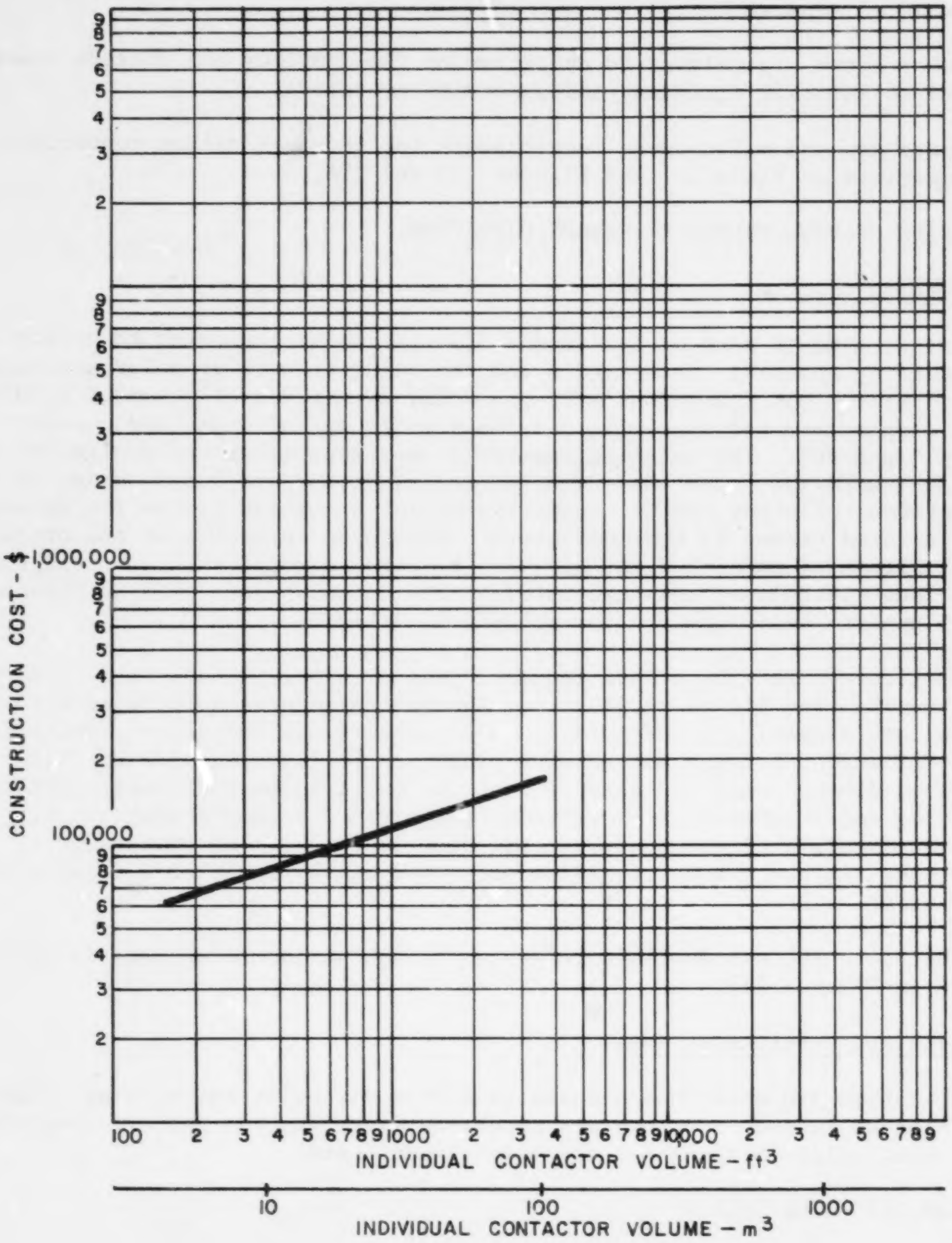


Figure 134. Construction cost for pressure carbon contactors.

included. A separate curve is provided for makeup carbon, and this cost must be added separately.

Labor costs are related to operation of the facility and include those required to maintain equipment and supervise operation.

Operation and maintenance requirements for pressure carbon contactors are summarized in Table 117 and Figures 135 and 136.

CONVERSION OF SAND FILTER TO CARBON CONTACTOR

Construction Cost

Existing rapid sand or dual-media filters can be converted to carbon contactors by removing filter media and replacing it with granular activated carbon. Filter box dimensions will generally permit installation of a 30 to 36 in. deep carbon bed that will provide 9 to 11 min of empty bed contact time at 2 gpm/ft^2. The existing underdrain and support gravel design can be retained unmodified. The only required modifications are installation of a spent carbon collector and transport system and a similar system for return of reactivated carbon to the contactors. Continued operation at the original design filtration rate of 2 gpm/ft^2 will require no modification of existing filter rate controls or instrumentation. The backwash rate will be reduced from 15 gpm/ft^2 to 10 gpm/ft^2 for activated carbon.

Cost curves were developed for modifying existing filters with total bed areas ranging from 350 to 70,000 ft^2. The costs include those related to removing and disposing of existing sand (or coal-sand) and gravel, installing carbon collection troughs and related piping and valving outside of filter, installing slurry pumps and related controls for transport of spent carbon to dewatering and regenerating facilities, reactivated carbon storage tank, reactivated carbon return eductors, and distribution piping systems to contactors. Carbon transport piping was sized on the basis of 3 lb of carbon/gal of water.

The costs for accomplishing these modifications are presented in Table 118 and in Figure 137.

Operation and Maintenance Cost

Operation and maintenance costs should be virtually the same as after conversion as before, and thus preconversion experience at the existing plant is the best guide to operation and maintenance costs.

GRANULAR ACTIVATED CARBON

Material Cost

Virgin carbon is generally purchased in 2-ft^3 bags for quantities of 40,000 lb and less, with larger quantities generally transported in bulk by rail. Costs were developed for purchase and placement of virgin carbon in a contactor. These costs may be used for either pressure or gravity carbon

Table 117

Operation and Maintenance Summary for Pressure Carbon Contactors

Total Surface Area (ft^2)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Process	Building	Total			
157	916	179,550	180,470	1,600	2,000	27,010
1,357	7,967	492,480	500,450	8,020	3,500	58,030
6,786	39,746	2,154,600	2,194,350	37,420	7,500	178,250

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

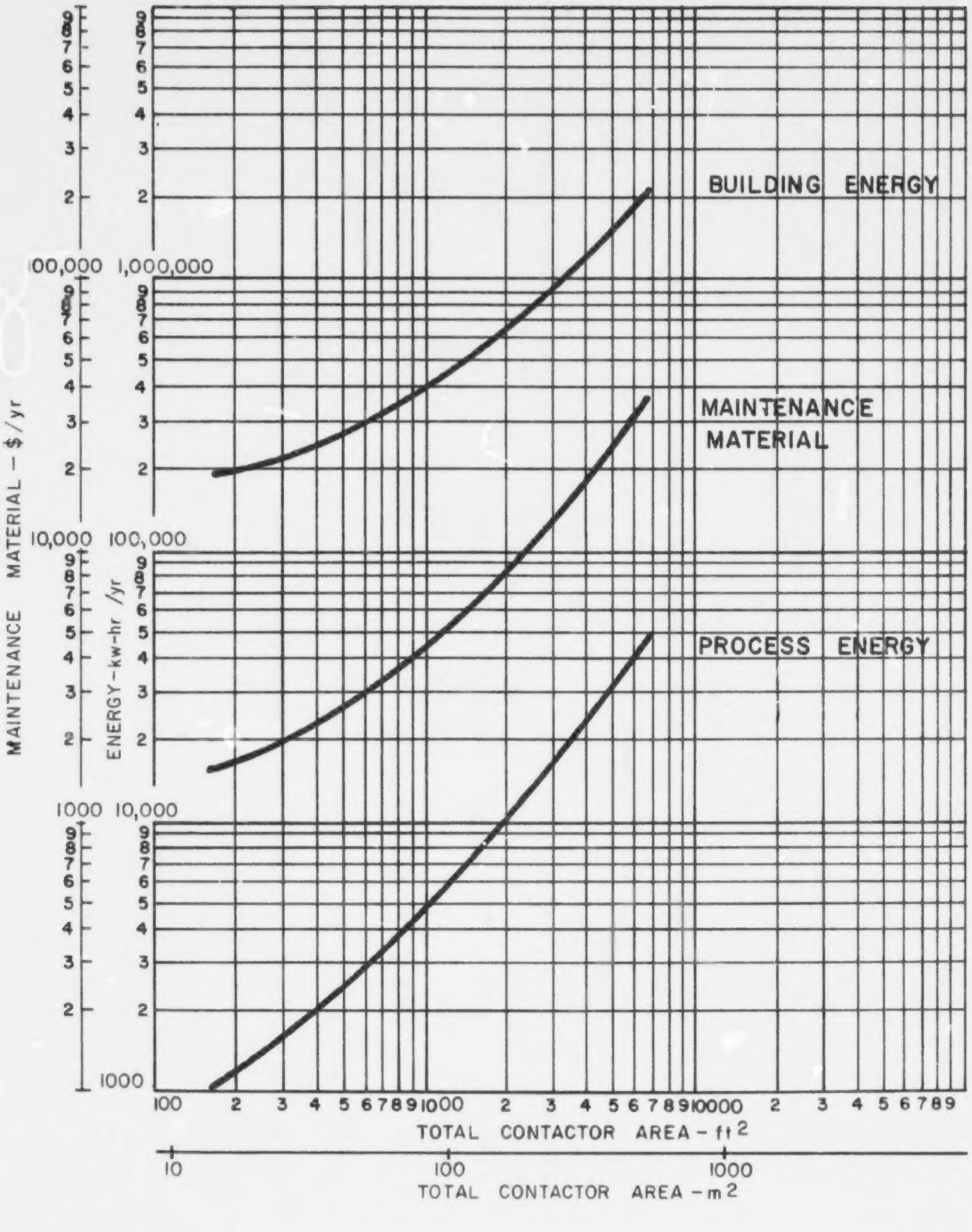


Figure 135. Operation and maintenance requirements for pressure carbon contactors - building energy, process energy, and maintenance material.

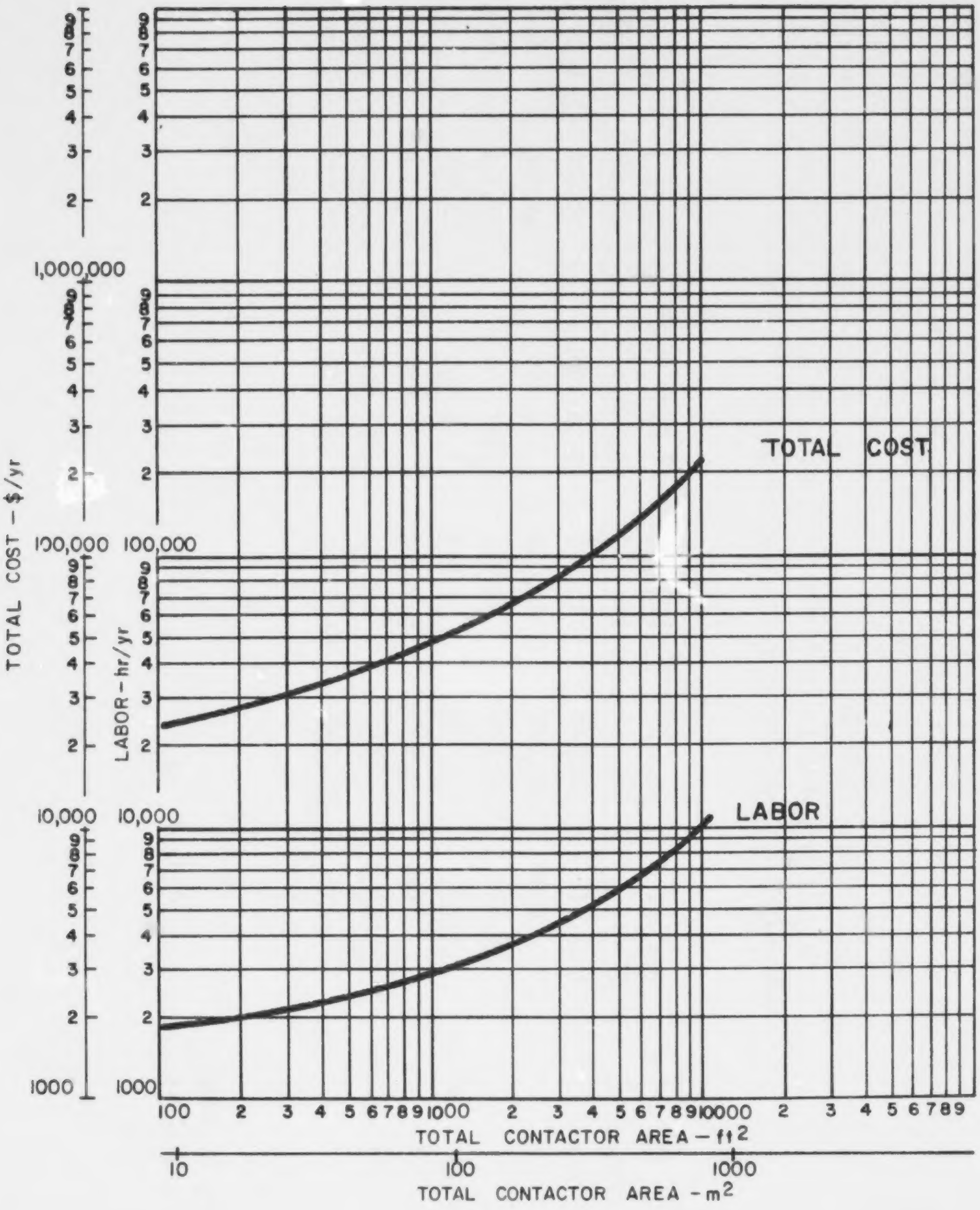


Figure 136. Operation and maintenance requirements for pressure carbon contactors - labor and total cost.

Table 118

Construction Cost for Conversion of Sand Filter to Carbon Contactor

Cost Category	Contactor Area (ft^2)* and Volume (ft^3)+					
	350 ft^2, 875 ft^3	1,750 ft^2, 4,375 ft^3	3,500 ft^2, 8,750 ft^3	17,500 ft^2, 43,750 ft^3	35,000 ft^2, 87,500 ft^3	70,000 ft^2 175,000 ft^3
Manufactured Equipment	$ 11,670	$ 22,280	$ 23,870	$ 85,400	$ 150,650	$ 294,930
Labor	8,620	28,270	48,030	174,900	338,970	646,400
Piping & Valves	10,470	52,240	84,770	443,780	893,410	1,644,380
Electrical & Instrumentation	1,730	3,300	3,540	12,560	22,300	43,970
SUBTOTAL	32,490	106,090	160,210	716,640	1,405,330	2,629,680
Miscellaneous & Contingency	4,870	15,910	24,030	107,500	210,800	394,450
TOTAL	37,360	122,000	184,240	824,140	1,616,130	3,024,130

*Area of existing filters.

+Assumes carbon bed dpeth of 30 in.

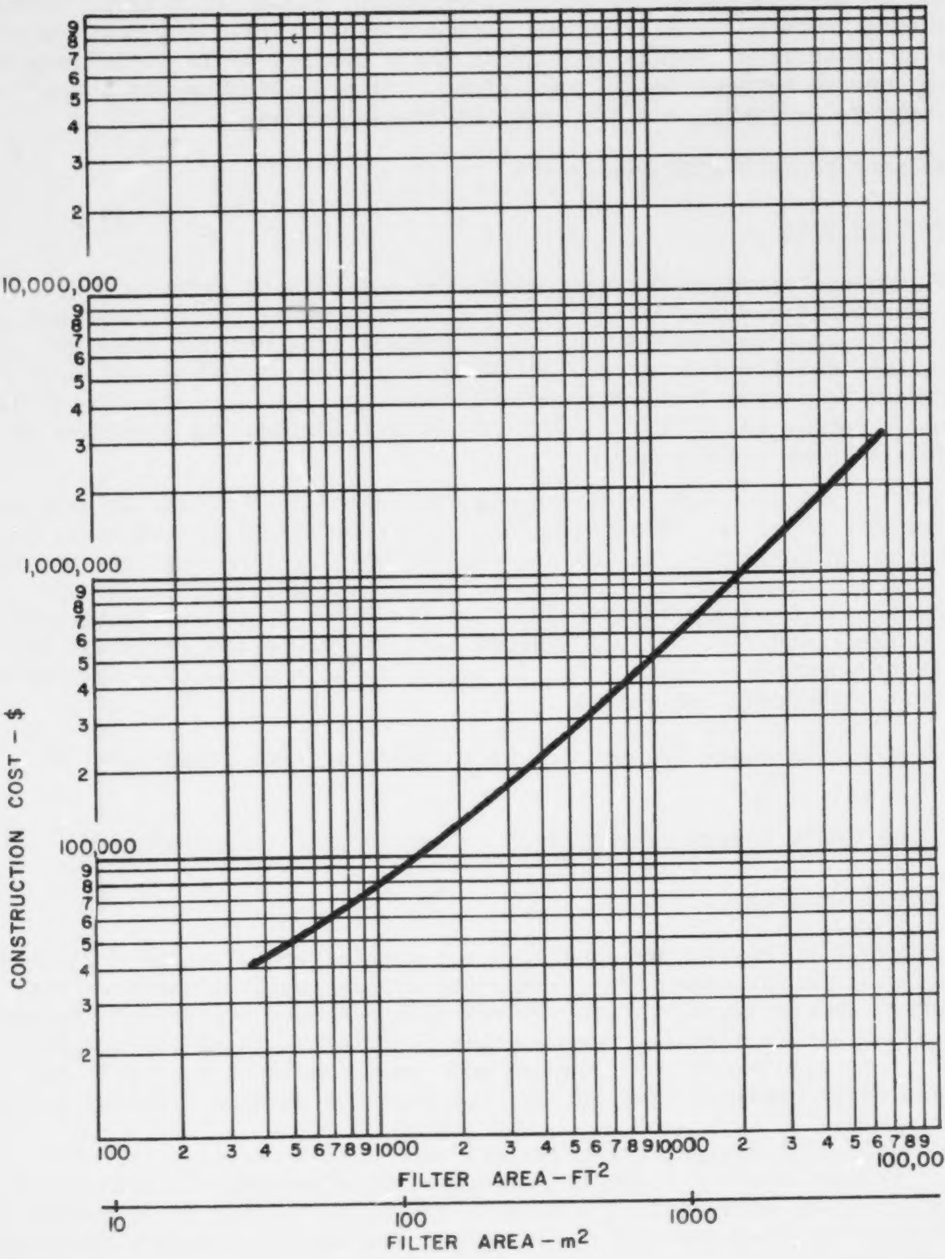


Figure 137. Construction cost for conversion of sand filter to carbon contactor.

contactors to obtain the complete cost of the carbon contactor. The curve may also be used to determine the cost of makeup carbon to replace carbon lost during contactor operation and carbon regeneration. The cost curve is presented in terms of pounds of carbon, and a density of 26 lb/ft^3 may be used to convert between volume and weight. Figure 138 presents a cost curve for purchase, delivery, and placement of virgin carbon.

CAPPING SAND FILTERS WITH ANTHRACITE

Construction Cost

A popular technique for increasing the capacity of existing rapid sand filter installations involves removing the top 6 to 12 in. of sand and replacing it with anthracite coal. The coarser coal permits suspended solids penetration into the filter bed, allowing operation of the filter beds at higher flow rates and for longer periods between backwash. In many situations, this modification can effect a 30 to 50 percent increase in capacity and a reduction in wash water usage.

Cost curves were developed assuming the removal of 12 in. of sand and replacement with 12 in. of anthracite coal for total filter bed areas ranging from 350 to 70,000 ft^2. The costs include labor for removing the sand from the filter and disposing of it on-site, material and freight costs for anthracite coal, and installation labor. The labor costs were developed assuming that sand removal from filters smaller than 3,500 ft^2 would be accomplished by manual labor. For larger filters, manual labor was supplemented with mechanical equipment.

Construction costs are summarized in Table 119 and illustrated in Figure 139.

OFF-SITE REGIONAL CARBON REGENERATION - HANDLING AND TRANSPORTATION

Construction Cost

Construction costs were developed for combination granular activated carbon dewatering/storage bins. These facilities would be required for storage and dewatering of carbon removed from pressure or gravity contactors before transport to off-site regeneration facilities. Such storage is generally provided where spent carbon must be accumulated before it can be economically handled, transported, and regenerated at a regional facility.

Two different design configurations were used to develop the cost curves. Storage bins of 2,000 ft^3 and less are elevated, 12 ft diameter, cylindrical tanks with conical bottoms. The 5,000 ft^3 bin is an elevated, three-hopper, rectangular tank. For larger storage requirements, multiple units would be used.

Tanks are elevated for gravity loading to dump trucks. The overall height of the storage bins was limited to 30 ft. All designs include stainless steel dewatering screens and associated piping and valving to conduct water to waste drains. Tanks are field fabricated of braced, 1/4 in., shop-formed steel plate protected by a suitable coating system. The tanks

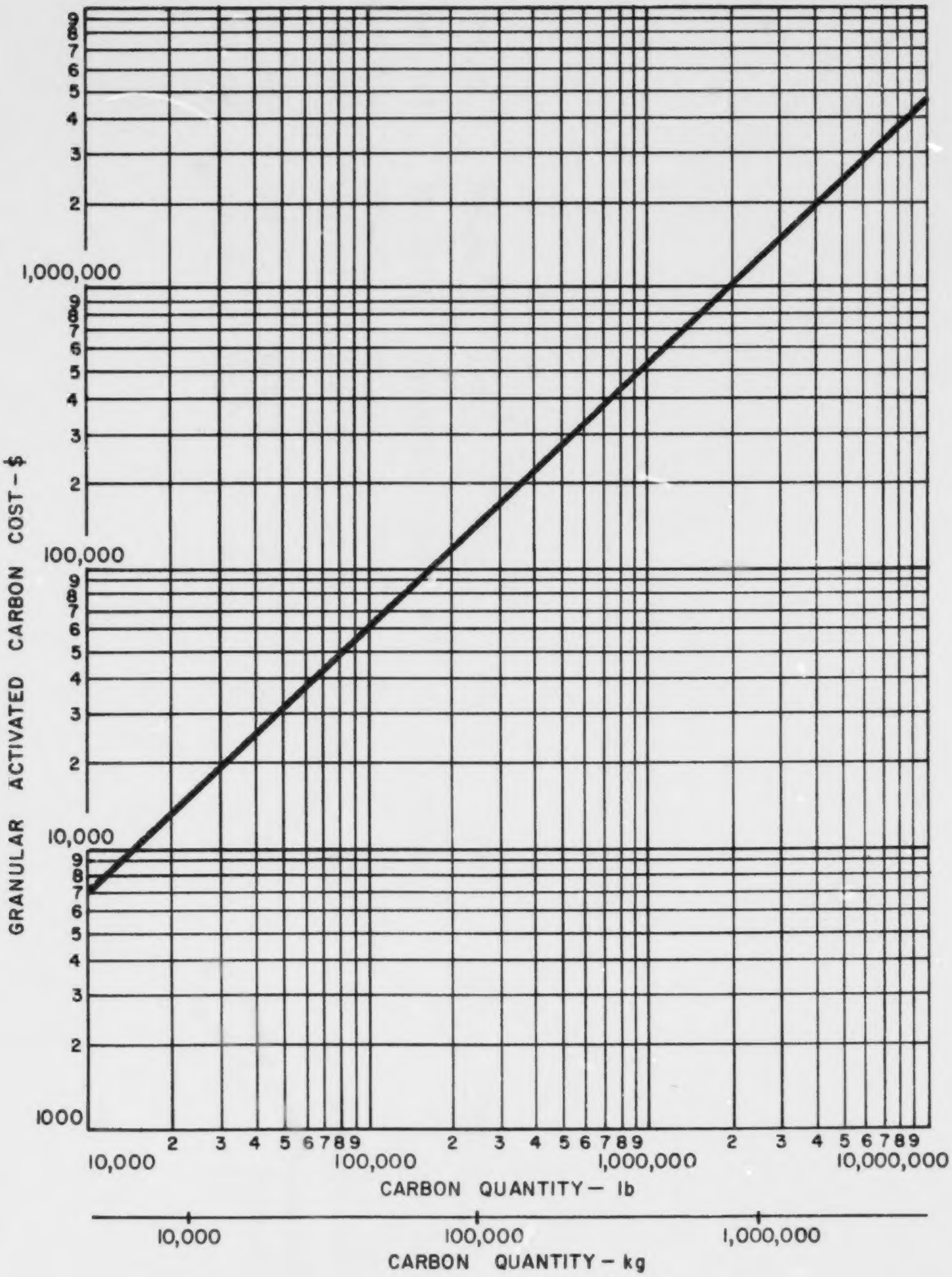


Figure 138. Material cost for granular activated carbon, including cost for purchase, delivery, and placement.

Table 119

Construction Cost for

Capping Sand Filters with Anthracite

	Filter Area (ft^2)					
Cost Category	350	1,750	3,500	17,500	35,000	70,000
Material	$1,390	$6,940	$11,600	$58,000	$116,000	$232,000
Labor	660	2,140	5,600	27,100	50,800	102,000
SUBTOTAL	2,050	9,080	17,200	85,100	166,800	334,000
Miscellaneous and Contingency	310	1,360	2,580	12,770	25,020	50,100
TOTAL COST	2,360	10,440	19,780	97,880	191,820	385,100

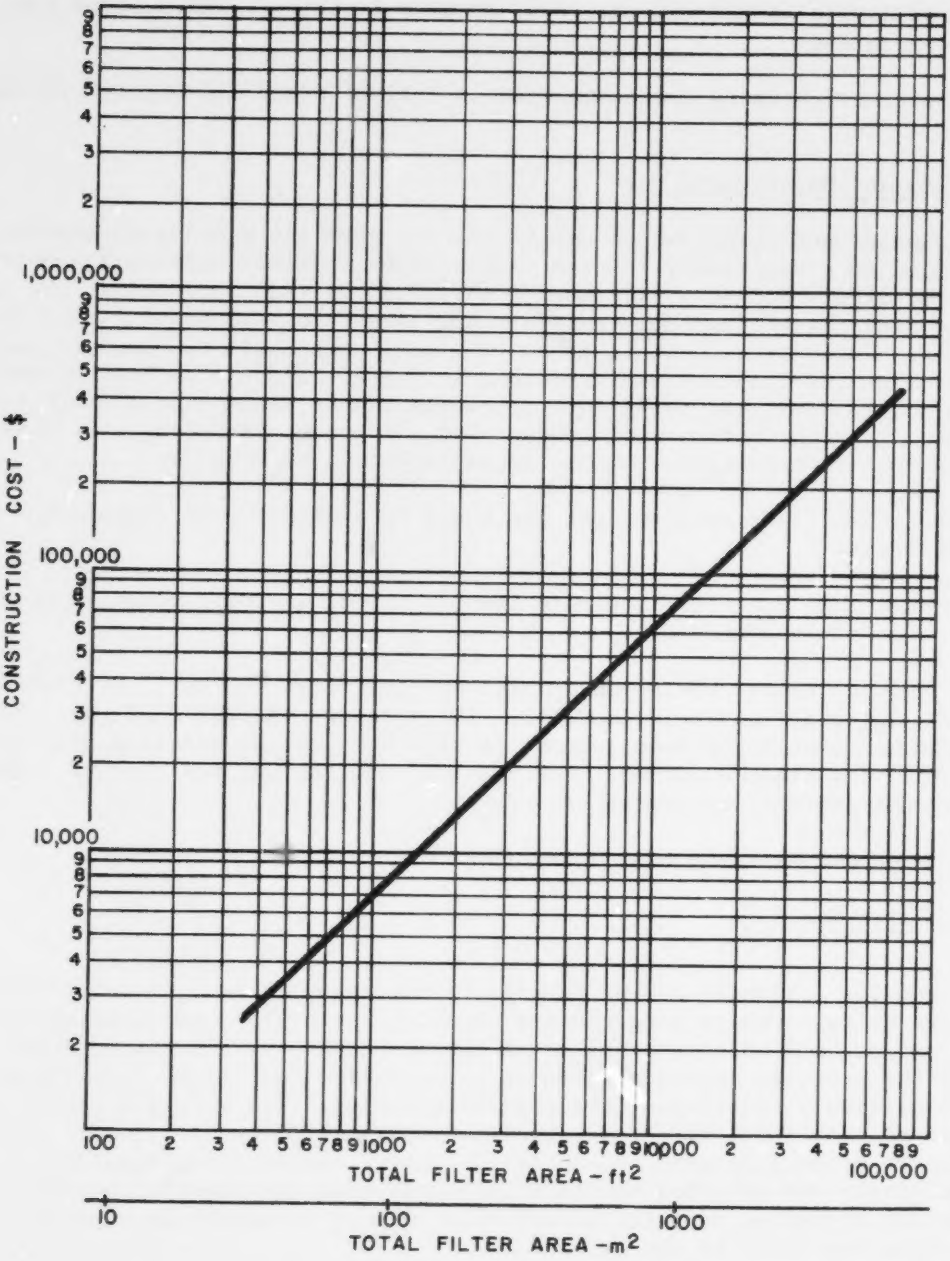


Figure 139. Construction cost for capping sand filters with anthracite.

are located outside and are supported on pier footings. No paving for the access area is included. No costs are included for trucks necessary to haul dewatered carbon to the regional regeneration facility. These costs must be added separately.

Construction costs are summarized in Table 120 and illustrated in Figure 140.

Operation and Maintenance Cost

Granular activated carbon may be removed from the contactor, dewatered, and hauled to a regionally located regeneration facility serving a number of treatment plants within a distance of up to 100 miles. Included in the costs are the fuel, labor, and maintenance requirements to load spent carbon from dewatered carbon storage tanks to 30 yd^3, semi-dump trailers, haul to the regeneration facility, unload, reload reactivated carbon from bulk storage, return to the treatment plant, and discharge either to on-site storage tanks or directly to the carbon contactors. For all travel distances it was assumed that the entire operation would be accomplished in an 8-hr day.

The annual fuel requirements are based on a diesel fuel consumption of 3.5 miles/gal.

Maintenance materials are only for the trucks and were computed assuming a unit cost of $0.30/mile.

A summary of the operation and maintenance requirements is presented in Table 121 and Figures 141 and 142. The total costs represent the labor, energy, and maintenance requirements related only to the handling and transportation of activated carbon. The costs do not include the cost of regeneration at the regional regeneration facility.

MULTIPLE HEARTH GRANULAR CARBON REGENERATION

Construction Cost

Granular activated carbon is effectively regenerated in multiple hearth furnaces by exposure to properly and closely controlled conditions of temperature, oxygen, and moisture content of the atmosphere within the furnace. During the process, adsorbed organics are oxidized and driven off, restoring the adsorptive properties of the activated carbon. The multiple hearth furnace is a cylindrical, refractory-lined shell carrying a series of fired refractory hearths located one above the other. A revolving insulated central shaft and attached radial rabble arms move the material across the hearth, directing material alternately outward or inward as material drops from one level to the next.

The required size of a multiple hearth furnace is a function of the required frequency of regeneration, the carbon dosage used (which is a function of the nature of the organics adsorbed), the allowable hearth loading of the furnace, and anticipated downtime. These factors must be considered in selecting the required furnace size.

Table 120

Construction Cost for

Off-Site Regional Carbon Regeneration - Handling and Transportation

Cost Category	On-Site Storage Capacity (ft^3)		
	1,000	5,000	20,000
Excavation and Sitework	$ 210	$ 370	$ 1,470
Manufactured Equipment	3,240	13,050	50,600
Concrete	1,170	1,750	6,360
Steel	5,630	30,900	122,500
Labor	12,090	29,430	123,640
Pipe and Valves	1,380	3,830	14,990
SUBTOTAL	23,720	79,330	319,560
Miscellaneous and Contingency	3,560	11,900	47,930
TOTAL	27,280	91,230	367,490

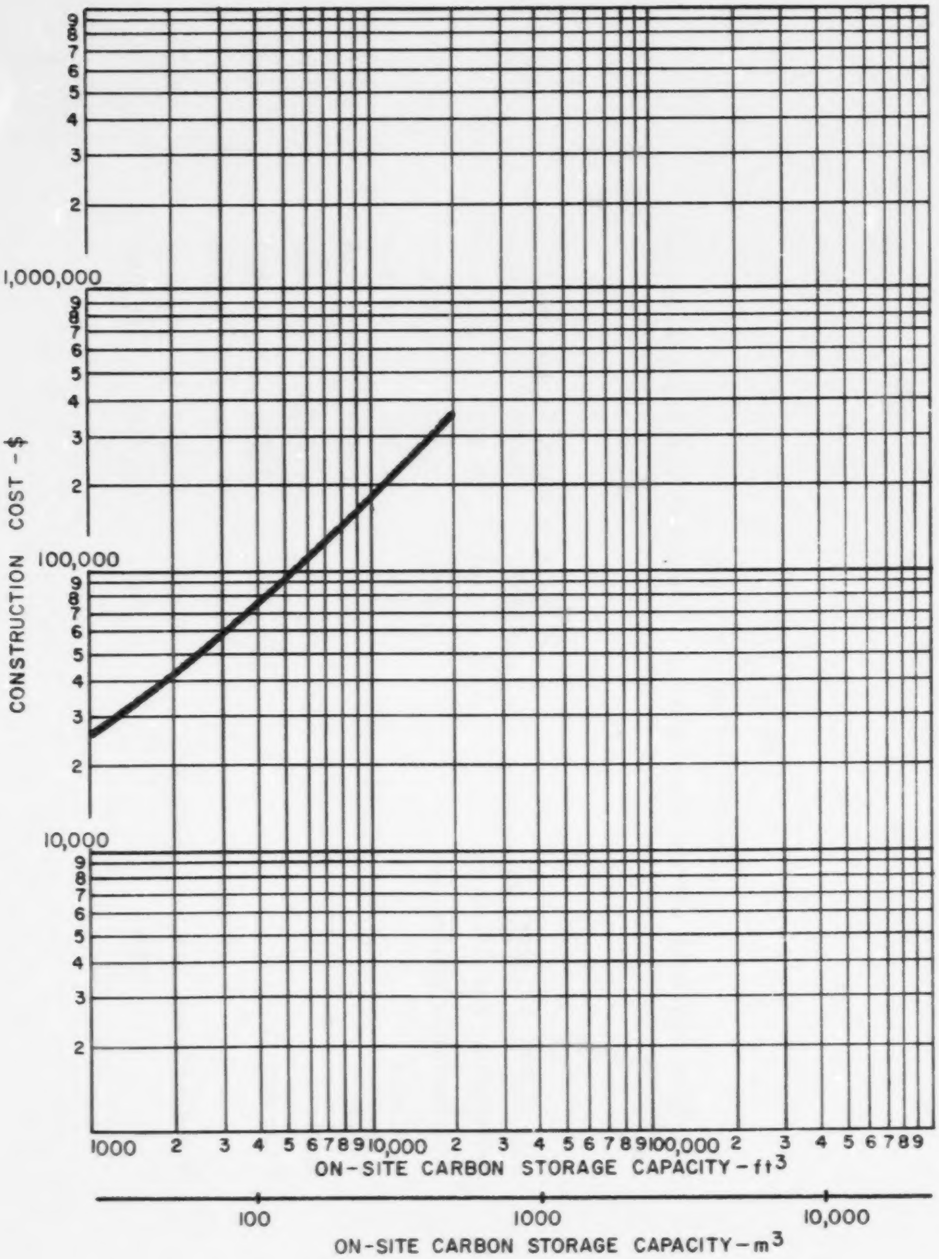


Figure 140. Construction cost for off-site regional carbon regeneration handling and transportation.

Table 121

Operation and Maintenance Summary for Off-Site Regional Carbon Regeneration Handling and Transportation

Carbon Regenerated (lbs/yr)	Diesel Fuel* (gal/yr)			Maintenance Material ($/yr)			Labor‡ (hr/yr)			Total Cost§ ($/yr)		
	10-mi+ haul	25-mi haul	100-mi haul	10-mi haul	25-mi haul	100-mi haul	10-mi haul	25-mi haul	100-mi haul	10-mi haul	25-mi haul	100-mi haul
30,000	5.7	14.3	57	6	20	60	6.8	11	14	80	140	230
150,000	28.6	71.4	286	30	90	320	34	55	70	380	670	1,150
500,000	97	243	971	110	280	1,090	116	187	238	1,310	2,260	3,910
1,000,000	194	486	1,943	210	550	2,180	232	374	476	2,620	4,510	7,810
3,000,000	582	1,430	5,829	650	1,640	6,540	780	1,200	1,428	8,710	14,280	23,440

*Based on 3.5 miles/gal for 30-yd^3 semi-dump truck.

+All distances are one-way.

‡Labor for loading and unloading carbon and for hauling.

§Calculated using diesel fuel at $0.45/gal and labor at $10.00/hr

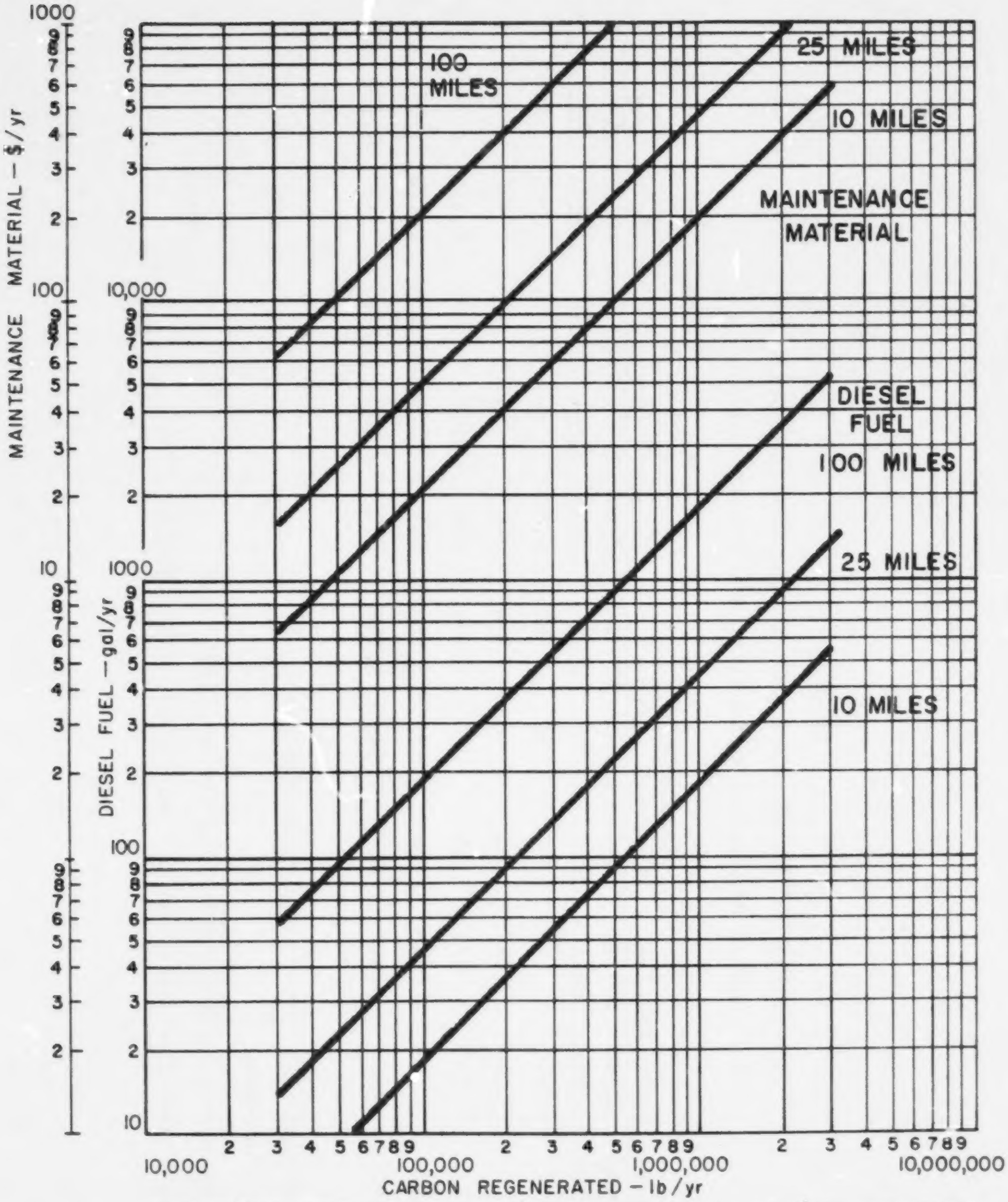


Figure 141. Operation and maintenance requirements for off-site regional carbon regeneration handling and transportation - diesel fuel and maintenance material needed for 10, 25, and 100-mile haul distances.

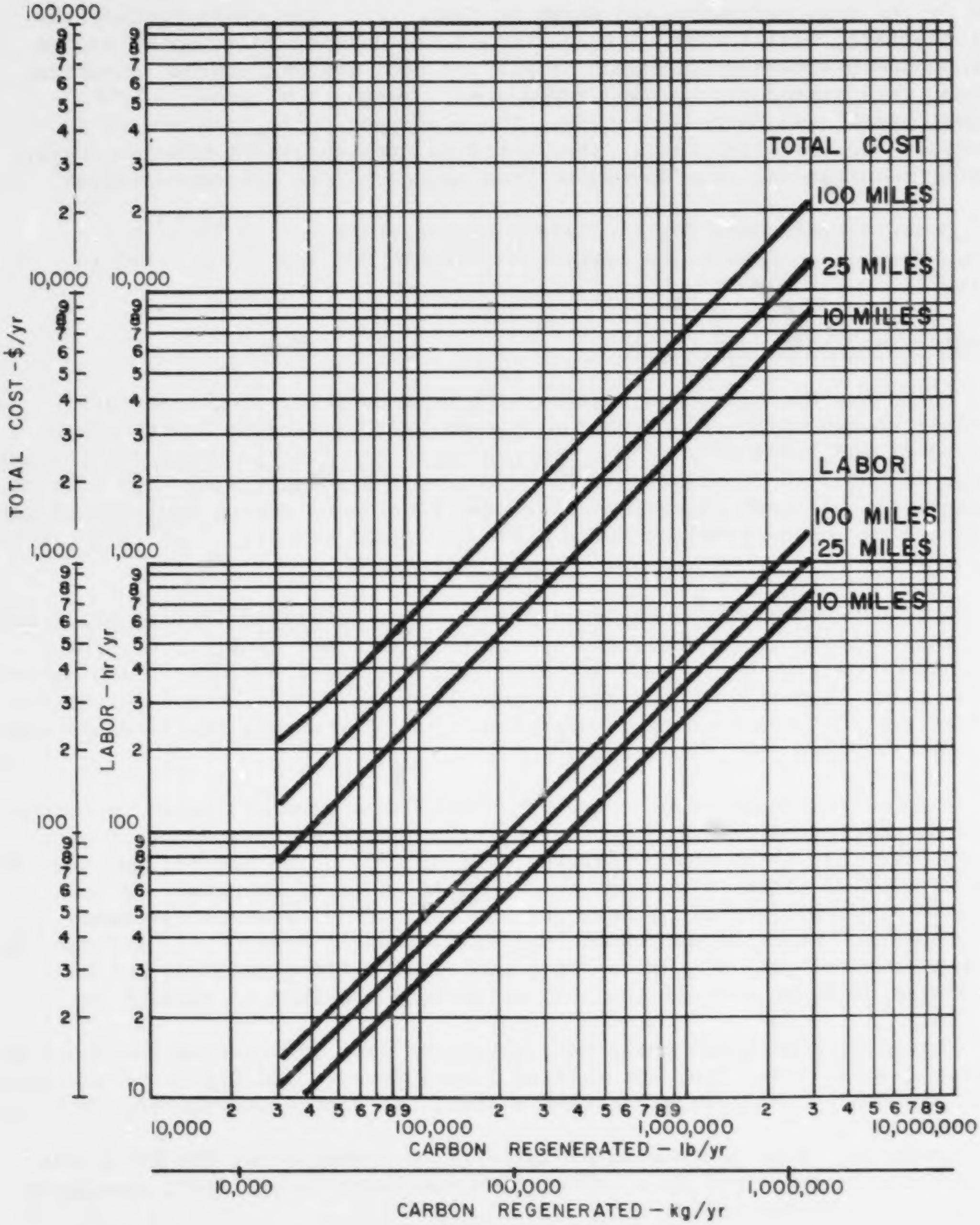


Figure 142. Operation and maintenance requirements for off-site regional carbon regeneration handling and transportation - labor and total cost for 10, 25, and 100-mile haul distances.

Construction costs were developed for a series of single furnaces with various hearth areas. Conceptual designs for multiple hearth furnaces used in the cost estimates are shown in Table 122. The costs include the basic furnace, center shaft drive, furnace and cooling fans, spent carbon storage and dewatering equipment, auxiliary fuel system, exhaust scrubbing system, regenerated carbon handling system, quench tank, steam boiler, control panel, and instrumentation. The equipment costs that are on a furnished and installed basis were obtained from equipment manufacturers. Housing requirements were developed from manufacturers' recommendations.

Construction costs for a complete carbon regeneration furnace and supporting equipment are presented in Table 123 and illustrated in Figure 143.

Operation and Maintenance Cost

Operation and maintenance costs were developed for single-furnace multiple hearth carbon regeneration systems, with effective hearth areas between 27 and 1,509 ft^2. The costs presented are for operation 100 percent of the time, and correction must be made once the actual percentage of time in operation has been determined. Process electrical energy and natrual gas requirements were determined using a hearth carbon loading of 40 to 50 lb/ft^2 per day.

Process electrical energy requirements were developed from manufacturers' information listing connected and operating horsepower requirements for furnaces of various sizes, and assuming that the furnace operates 100 percent of the time. Appropriate correction must be made for the actual percentage of the time that the furnace is operated. Building energy requirements are only for lighting and ventilation.

Natural gas requirements were calculated from manufacturers' recommendations assuming that the feed activated carbon has a moisture content of 50 percent and that the furnace operates continuously. The natural gas requirement must be adjusted to account for the percentage of downtime. A heat value of 1,000 BTU/scf of natural gas was assumed in determining energy requirements. Where an alternate fuel such as No. 2 Fuel Oil is utilized in place of natural gas, the appropriate number of gallons required can be calculated using an overall fuel BTU value equal to that of natural gas.

Maintenance material costs were developed from information furnished by equipment suppliers. They are related to maintenance and repair of electrical drive machinery, replacement of rabble arms, and damaged refractory materials.

Operating labor is related principally to operation of the equipment. Estimates were developed from information furnished by equipment suppliers and operating installations.

Table 124 presents the operation and maintenance requirements, which are also shown in Figures 144 and 145.

Table 122

Conceptual Design for Multiple Hearth Granular Carbon Regeneration

Furnace Configuration			
Effective Hearth Area (ft^2)	I.D.	Number of Hearths	Building Area Requirements (ft^2)
27	30"	6	750
37	30"	6	750
147	39"	6	900
359	10'-6"	5	1,200
732	14'-6"	6	1,800
1,509	20'-0"	6	2,400

Table 123

Construction Cost for

Multiple Hearth Granular Carbon Regeneration

Cost Category	Furnace Hearth Area (ft^2)					
	27	37	47	359	732	1,509
Manufactured Equipment	$220,660	$ 275,830	$ 519,830	$ 647,140	$1,039,660	$ 1,304,880
Labor	117,720	147,150	273,280	346,850	557,060	704,210
Pipe and Valves	8,330	8,330	8,330	14,480	23,450	48,800
Electrical and Instrumentation	8,290	8,340	8,340	9,190	14,930	26,980
Housing	109,670	109,670	124,230	175,100	245,790	334,460
SUBTOTAL	464,670	549,320	934,010	1,192,760	1,880,890	2,419,330
Miscellaneous and Contingency	69,700	82,400	140,100	178,910	282,130	362,900
TOTAL	534,370	631,720	1,074,110	1,371,670	2,163,020	2,782,230

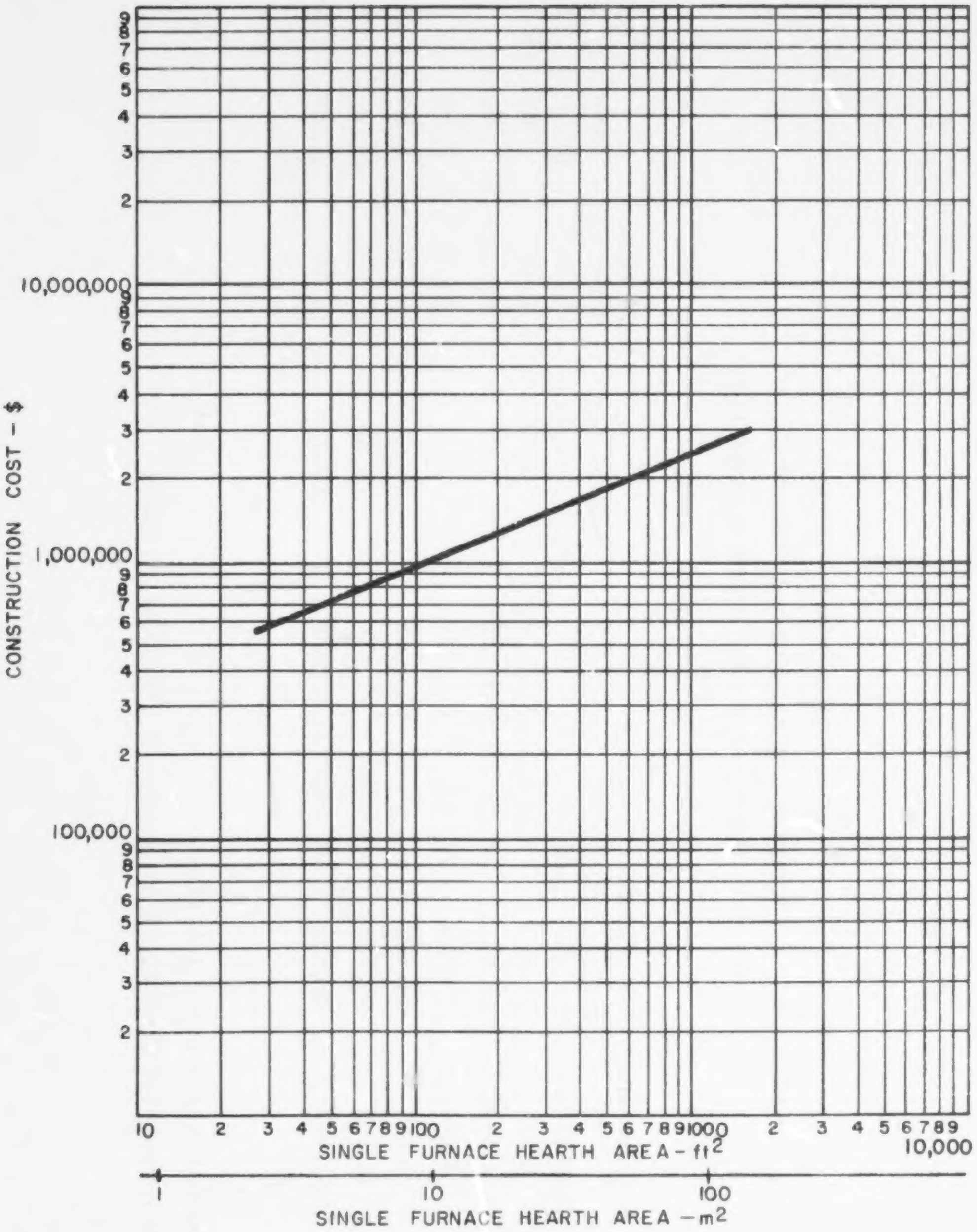


Figure 143. Construction cost for multiple hearth granular carbon regeneration.

Table 124

Operation and Maintenance Summary for Multiple Hearth Granular Carbon Regeneration

Effective Hearth Area (ft^2)	Regenerated Carbon (lb/day)	Electrical Energy (kw-hr/yr) Building	Electrical Energy (kw-hr/yr) Process	Electrical Energy (kw-hr/yr) Total	Natural Gas (scf/yr x 10^6)	Maintenance Material ($/yr)*	Labor (hr/yr)	Total Cost+ ($/yr)
27	1,224	14,630	261,400	276,030	5.80	$ 2,990	900	$ 27,810
37	1,670	14,630	326,750	341,380	7.72	3,740	950	33,520
147	6,624	17,550	424,770	442,320	26.2	6,410	3,400	87,740
359	13,680	23,400	588,150	611,550	48.26	8,550	6,200	151,630
732	32,400	35,100	849,550	884,650	108.40	11,760	10,500	284,220
1,509	66,960	46,800	1,307,000	1,353,800	207.75	16,040	17,000	496,730

*Makeup carbon costs are not included.

+Calculated using $0.03/kw-hr, $0.0013/scf and $10.00/hr of labor.

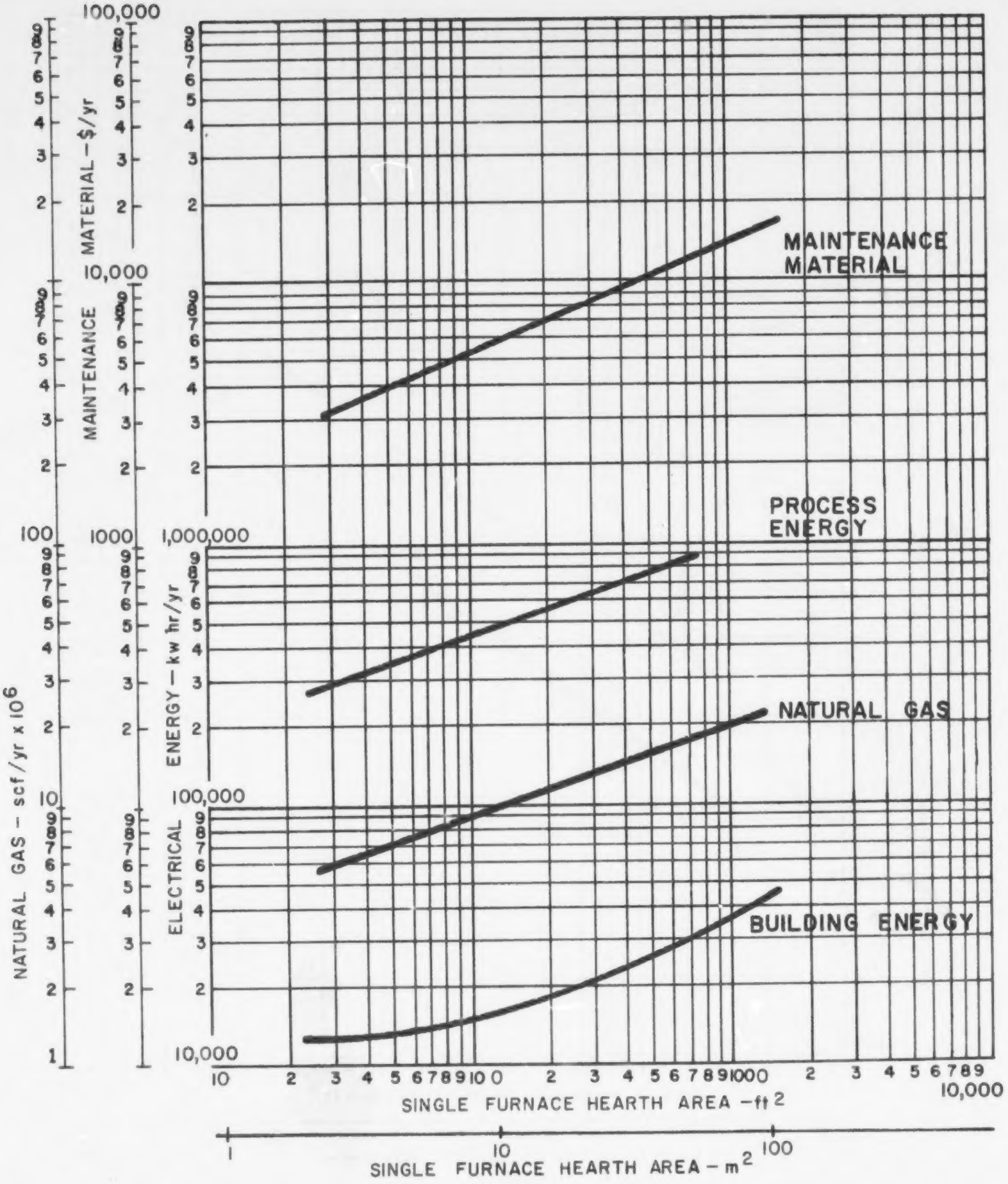


Figure 144. Operation and maintenance requirements for multiple hearth granular carbon regeneration - building energy, process energy, natural gas, and maintenance material.

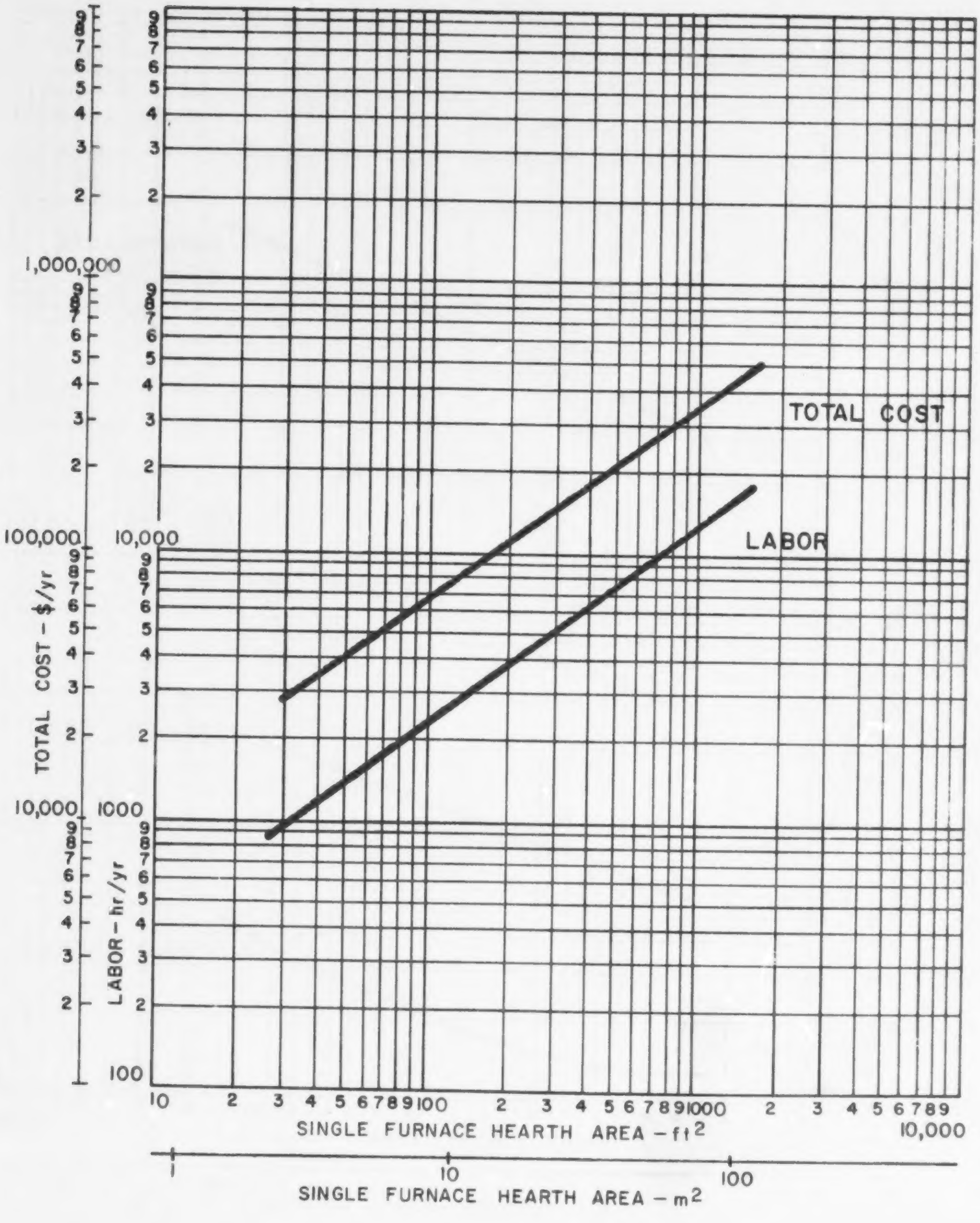


Figure 145. Operation and maintenance requirements for multiple hearth granular carbon regeneration - labor and total cost.

INFRARED CARBON REGENERATION FURNACE

Construction Cost

Granular activated carbon can be regenerated in furnaces using infrared energy as the heat source. Only electrical power is required to operate the furnace. In an infrared furnace, the carbon is moved through the furnace on a conveying belt that passes the carbon beneath infrared heating elements in a controlled atmosphere. Reactivation time can be varied by controlling conveyor speed and/or varying the depth of carbon on the belt. The furnaces are factory constructed in modules of various widths, which allows assemblage of furnaces with a wide range of regeneration capacities. The smallest furnace will economically process carbon quantities of as low as 100 lb/hr, which makes this process attractive for small installations. The largest unit will process approximately 60,000 lb/day. Another advantage of infrared furnaces is that the furnace design permits start-stop operation without furnace damage or excessive operating cost.

Conceptual designs were developed using information provided by the equipment manufacturer (Table 125). Construction costs were developed as a function of pounds per day of regeneration capacity, and are based on manufacturers' design and loading parameters. The costs include the premanufactured furnace modules (drying, pyrolysis, and activation), spent carbon holding tank, dewatering feed screw, quench tank, after burner, wet scrubber, exhaust gas blower, all duct work, scrubber water piping and valving within process limits, and process electrical equipment and controls.

The equipment is entirely housed in a prefabricated metal building erected on a slab foundation. Open sidewall construction was assumed for the furnace area to facilitate heat removal.

Construction costs are presented in Table 126 and are illustrated in Figure 146.

Operation and Maintenance Cost

Operation and maintenance requirements and associated costs were developed with the aid of information furnished by the manufacturer. Although the process is relatively new and operational experience is somewhat limited, operational data from the few full-scale installations that are in service was found to agree with that reported in manufacturers' technical bulletins. It is especially important to note that the yearly operational requirements presented assume 24-hr/day operation, 7 days/week, and 365 days/year.

Process energy requirements are related to operation of the infrared heating units, cooling and exhaust blowers, and the scrubbing water system. Building energy is for lighting and ventilation only.

Maintenance material includes the replacement cost of tungsten filament quartz heating units that have a life expectancy of about 5,000 hr, replacement of small moving parts associated with dewatered carbon hauling and the scrubbing system, and general equipment maintenance.

Table 125

Conceptual Design for

Infrared Carbon Regeneration Furnace

Unit Capacity (lbs/day)	Furnace Size Width by Length (ft)	Building Area Requirements (ft^2)
2,400	4 x 20	480
16,800	7 x 48	2,500
38,400	8.5 x 72	3,900
60,000	9.5 x 100	6,000

Table 126

Construction Cost for

Infrared Carbon Regeneration Furnace

Cost Category	Furnace Capacity (lb/day)			
	2,400	16,800	38,400	60,000
Manufactured Equipment	$160,000	$ 360,000	$ 620,000	$ 940,000
Labor	48,000	100,000	174,000	235,000
Pipe and Valves	3,500	5,500	7,500	10,000
Electrical & Instrumentation	21,000	53,000	81,000	113,000
Housing	21,000	60,000	82,000	149,000
SUBTOTAL	253,500	578,500	964,500	1,447,000
Miscellaneous & Contingency	38,030	86,780	144,680	217,050
TOTAL COST	291,530	665,280	1,109,180	1,664,050

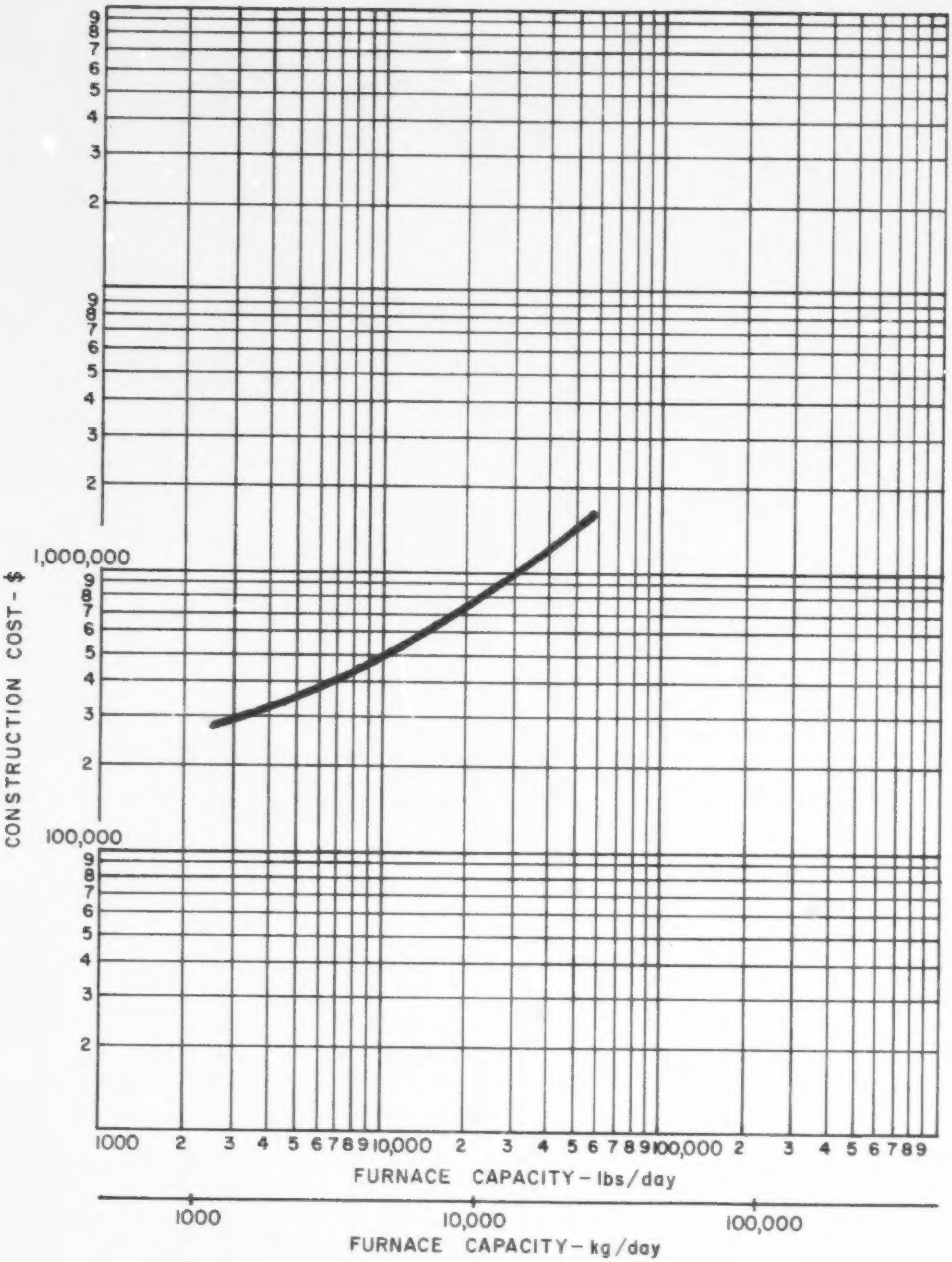


Figure 146. Construction cost for infrared carbon regeneration furnace.

Labor requirements are for operation and maintenance of the equipment. Operating attention is required only to oversee performance of the equipment and make occasional process adjustments. Maintenance attention is required on an infrequent basis, principally to service moving parts.

Operation and maintenance requirements are summarized in Table 127 and are also presented in Figures 147 and 148.

GRANULAR CARBON REGENERATION - FLUID BED PROCESS

Construction Cost

Recently an improved fluid bed furnace (FBF) has been developed for regeneration of granular activated carbon and is performing successfully at several installations. Unlike other FBF, this furnace does not utilize an inert heat source medium such as sand. The granular carbon is maintained in a fluidized condition by hot gases and is regenerated in the process. Regeneration of granular carbon has been accomplished at capacities approaching 70 lb/hr per ft^2 of reactor bed area. The process promises to have widespread application for regeneration of granular carbon.

Construction costs were developed for a complete FBF system, which includes spent and regenerated carbon storage, carbon dewatering system, the fluid bed reactor, fluidizing air blower, quench tank, particulate scrubber, interconnecting piping and electrical equipment within process area limits, and controls and instrumentation. Costs were supplied by the manufacturer on a furnished and installed basis for furnace capacities ranging from 6,000 to 24,000 lb/day. The furnaces were sized by the manufacturer using a loading rate of 70 to 73 lb/hr per ft^2 of reactor bed area. Furnaces are housed in a steel building 35 ft in overall height for protection from adverse weather. Table 128 presents the conceptual design utilized in the cost estimates.

The construction costs are presented in Table 129 and Figure 149.

Operation and Maintenance Cost

Process electrical requirements were provided by the manufacturer and represent average operating conditions. Continuous 24-hr/day, 365-day/year operation was assumed in calculating energy and other operation and maintenance requirements. The major electrical requirement is for the fluidizing air blower.

Natural gas requirements were computed from manufacturers' reported regeneration heat requirements of 2,000 BTU/lb of carbon. In addition, it was assumed that natural gas was used to provide regenerating steam at 0.75 lb/lb of carbon regenerated. A natural gas heating value of 1,000 BTU/scf was used to determine fuel requirements. Where an alternate fuel such as No. 2 fuel oil is utilized in place of natural gas, the appropriate number of gallons required can be determined using a total fuel BTU value equal to that of natural gas.

Table 127

Operation and Maintenance Summary for Infrared Carbon Regeneration Furnace

Carbon Regeneration Rate (lbs/day)	Energy (kw hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
2,400	7,540	701,680	709,220	8,900	2,380	53,980
16,800	39,300	4,522,000	4,561,300	21,000	4,900	206,840
38,400	61,300	10,206,000	10,267,300	28,000	9,380	429,820
60,000	94,300	15,820,000	15,914,300	33,600	13,300	644,030

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

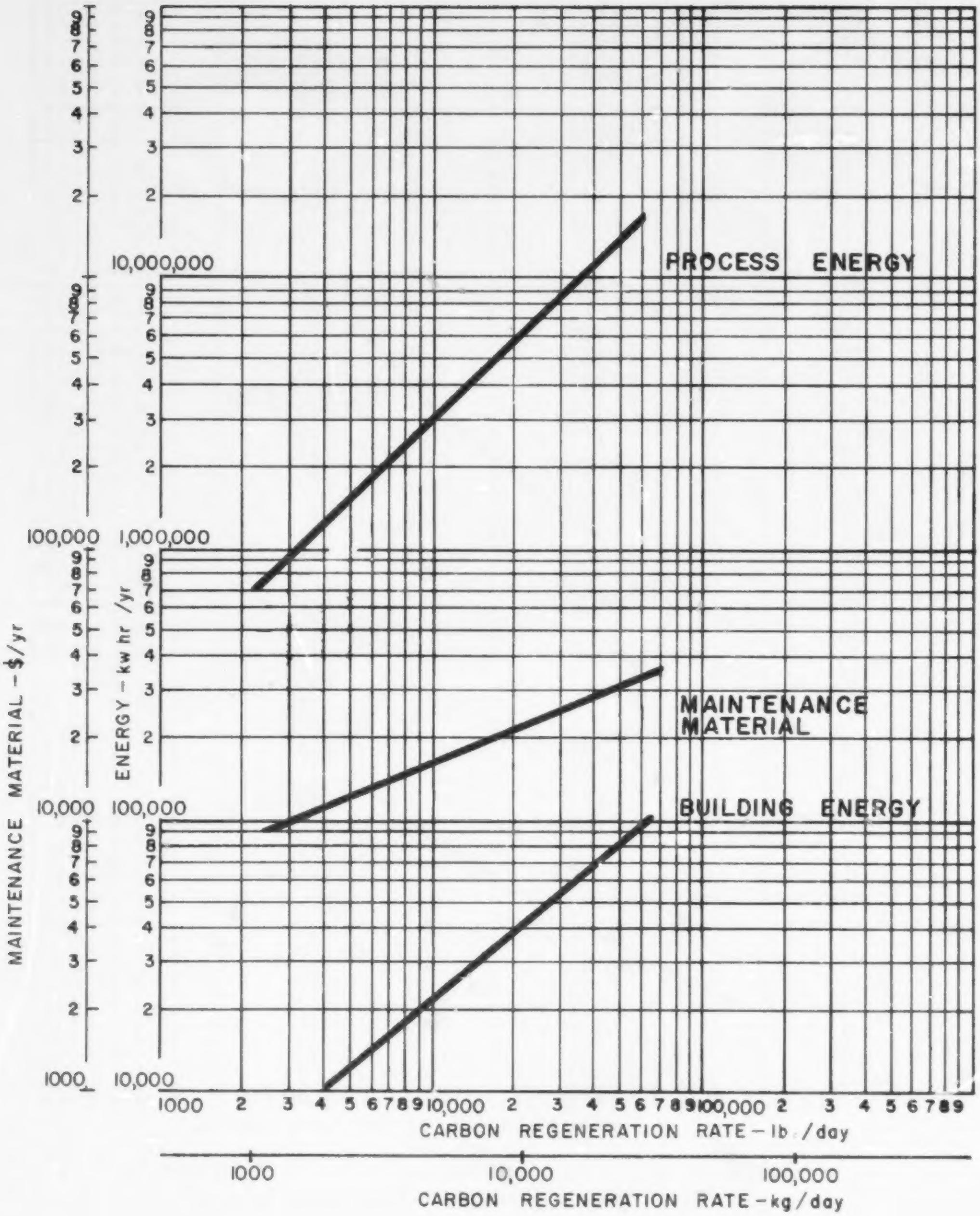


Figure 147. Operation and maintenance requirements for infrared carbon regeneration furnace - building energy, process energy, and maintenance material.

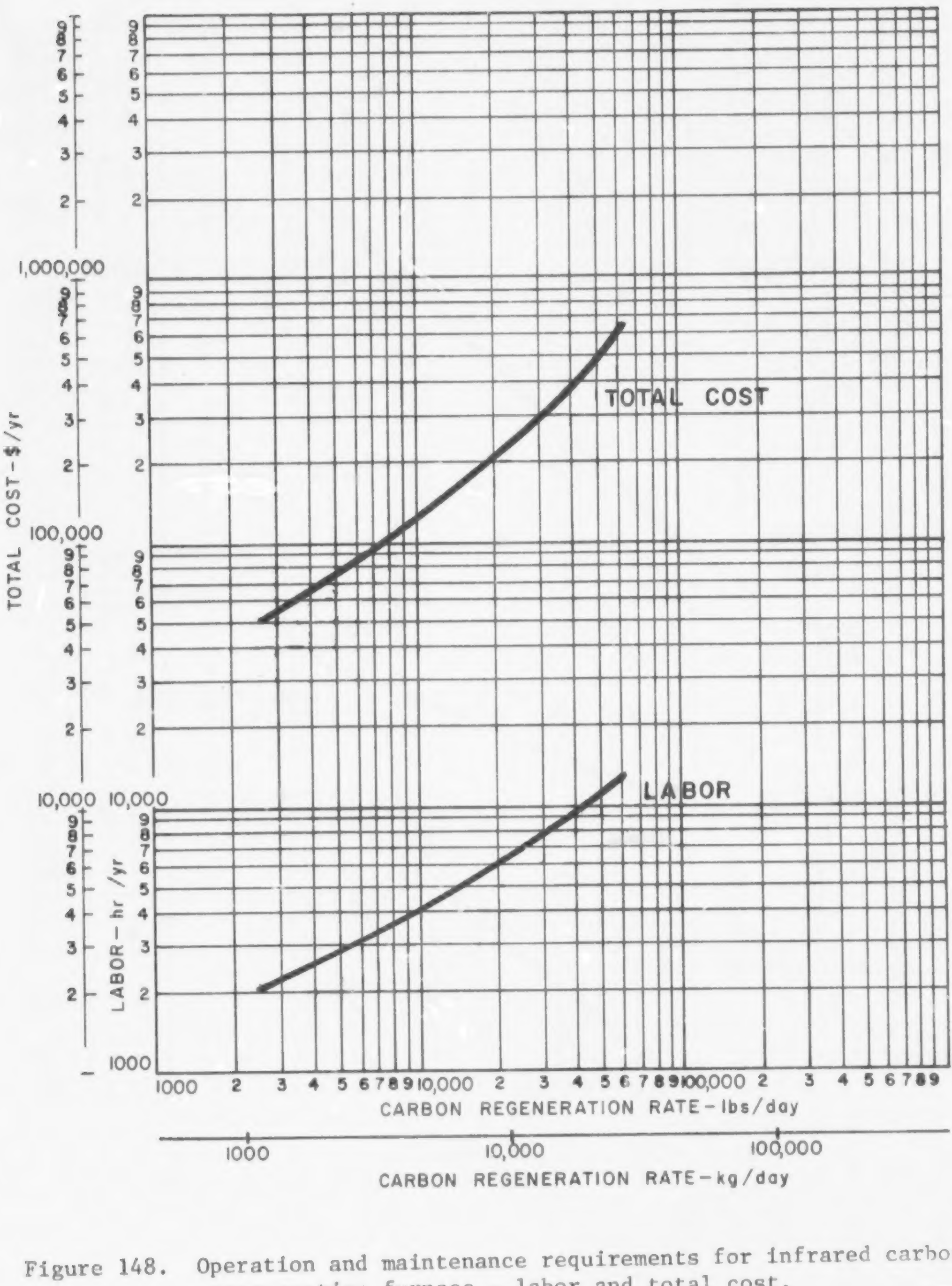


Figure 148. Operation and maintenance requirements for infrared carbon regeneration furnace - labor and total cost.

Table 128

Conceptual Design for Granular Carbon Regeneration - Fluid Bed Process

Carbon Regeneration Capacity (lbs/day)	Reactor Bed Area (ft^2)	Housing Requirements (ft^2)
6,000	4	1,400
12,000	8	1,800
18,000	12	2,200
24,000	16	2,600

Table 129

Construction Cost for
Granular Carbon Regeneration - Fluid Bed Process

Cost Category	Carbon Regeneration Capacity (lb/day)			
	6,000	12,000	18,000	24,000
Manufactured Equipment	$ 570,000	$ 650,000	$ 710,000	$ 755,000
Labor	180,000	205,000	225,000	240,000
Electrical and Instrumentation	10,000	11,000	11,000	12,000
Housing	60,000	75,000	90,000	106,000
SUBTOTAL	820,000	941,000	1,036,000	1,113,000
Miscellaneous and Contingency	123,000	141,150	155,400	166,950
TOTAL COST	943,000	1,082,150	1,191,400	1,279,950

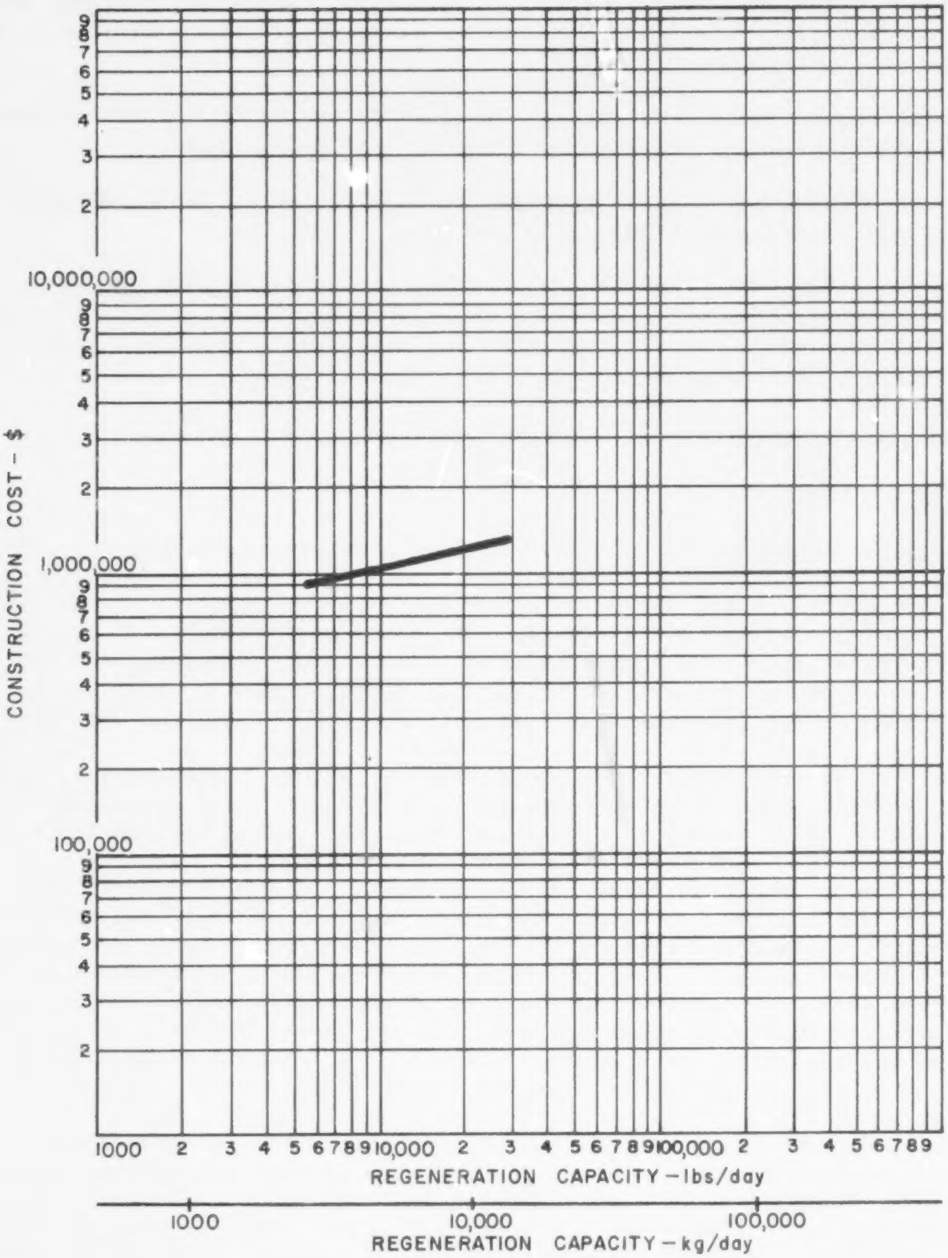


Figure 149. Construction cost for granular carbon regeneration - fluid bed process.

Maintenance material costs were estimated by the manufacturer at 2 percent of equipment capital costs. The maintenance material includes replacement parts for electrical drive machinery, damaged refractory materials, and other general maintenance items.

Labor requirements were related directly to operation and maintenance of the equipment and were furnished by the equipment manufacturer.

Operation and maintenance requirements are listed in Table 130 and illustrated by curves in Figures 150 and 151.

It should be noted that these requirements are for 24-hr/day operation. To estimate the requirements for less than 24-hr/day operation, it is recommended that the value for the operation and maintenance component be multiplied by the ratio of hours per day of operation divided by 24.

POWDERED CARBON REGENERATION - FLUIDIZED BED PROCESS

Construction Cost

Powdered activated carbon has been successfully regenerated on a pilot scale using a fluidized bed furnace (FBF). However, the lack of full-scale experience contributes a degree of uncertainty to the validity of the design criteria and resulting cost estimates. In spite of the lack of full-scale operating information, the cost estimate is adequately supported by the similarity of design criteria, capital and operating cost information, and operating power requirements that were obtained from several manufacturers.

The FBF system consists of a vertical, refractory-lined steel cylinder with an orificed grid in the lower section to support a bed of graded silica sand. Air at about 7 psig is introduced into the windbox beneath the orificed grid in sufficient quantity to fluidize the sand bed. A fuel source is added along with the fluidizing air to maintain a temperature of 1,300°F within the glowing mass of sand. The large reservoir of uniformly heated sand stabilizes the regeneration of the powdered carbon. Wet, spent carbon is added above the sand layer, and regenerated carbon is separated from the fluidizing sand and withdrawn at the base of the unit. A small amount of carbon along with ash is swept out with exhaust gases, where it is captured by a cyclone separator and a venturi scrubber. A schematic flow diagram for the regeneration system is shown in Figure 152.

Construction costs were developed for complete FBF systems, which included the fluidized bed reactor, cyclone and venturi separators, heat exchangers, fluidizing air blower, carbon feed and removal equipment, process pumps and piping, and controls and instrumentation. The furnaces were sized using a loading of 3 lb of carbon/ft^2 per hr, a loading rate that has been used successfully in pilot tests. Furnaces were assumed to be located out of doors, and no housing costs are included.

The construction costs are presented in Table 131 and also in Figure 153.

Table 130

Operation and Maintenance Summary for Granular Carbon Regeneration - Fluid Bed Process

Carbon Regeneration Rate (lb/day)	Process Energy (kw-hr/yr)	Natural Gas (scf/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
6,000	131,400	6,830,700	$ 15,540	2,400	$ 52,360
12,000	262,800	13,660,000	17,940	2,650	70,080
18,000	394,200	20,440,000	19,400	3,050	88,300
24,000	525,600	27,322,860	20,860	3,330	105,450

*Calculated using $0.03/kw-hr, $0.0013/scf for natural gas, and $10.00/hr of labor.

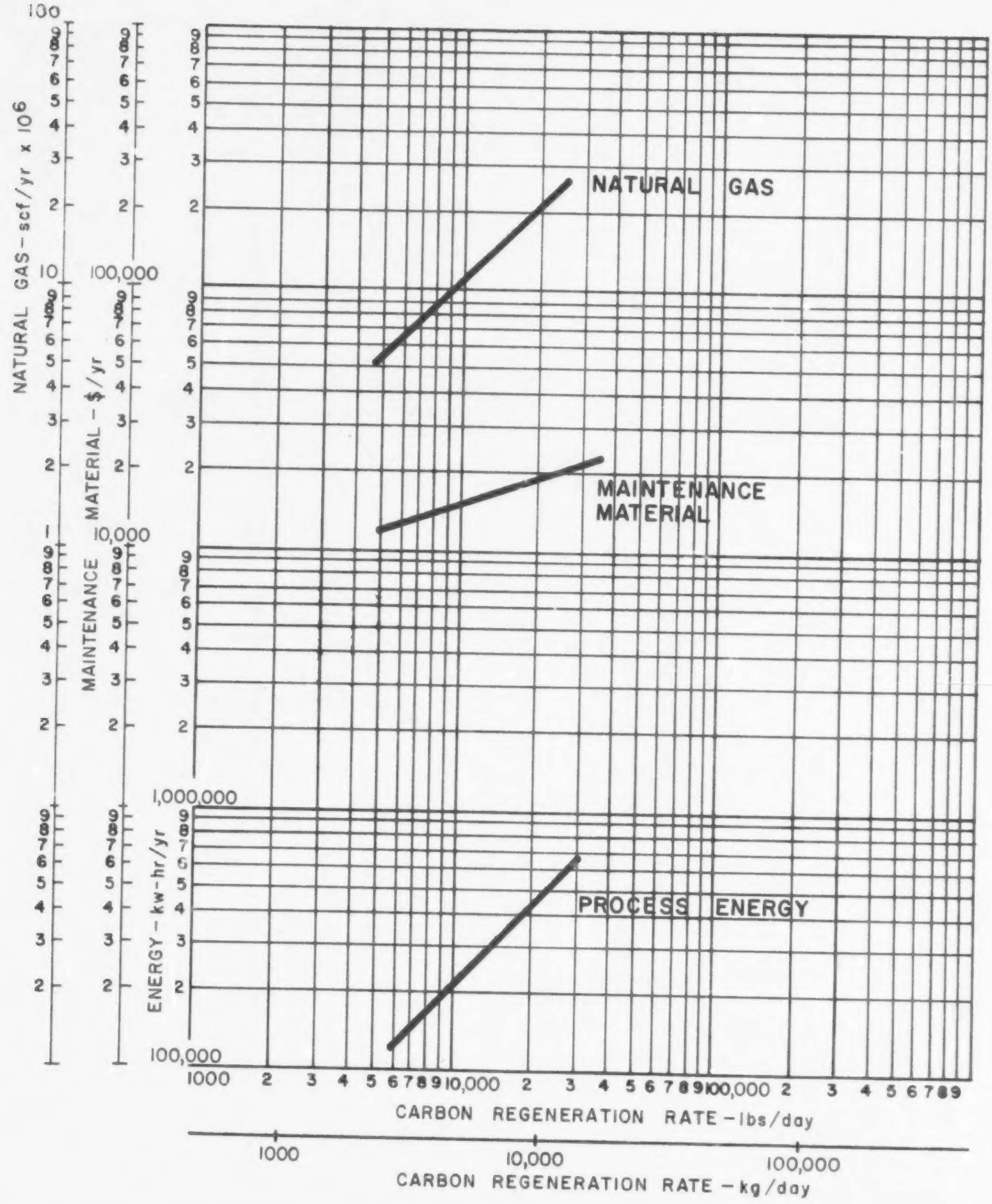


Figure 150. Operation and maintenance requirements for granular carbon regeneration, fluid bed process - natural gas, process energy and maintenance material.

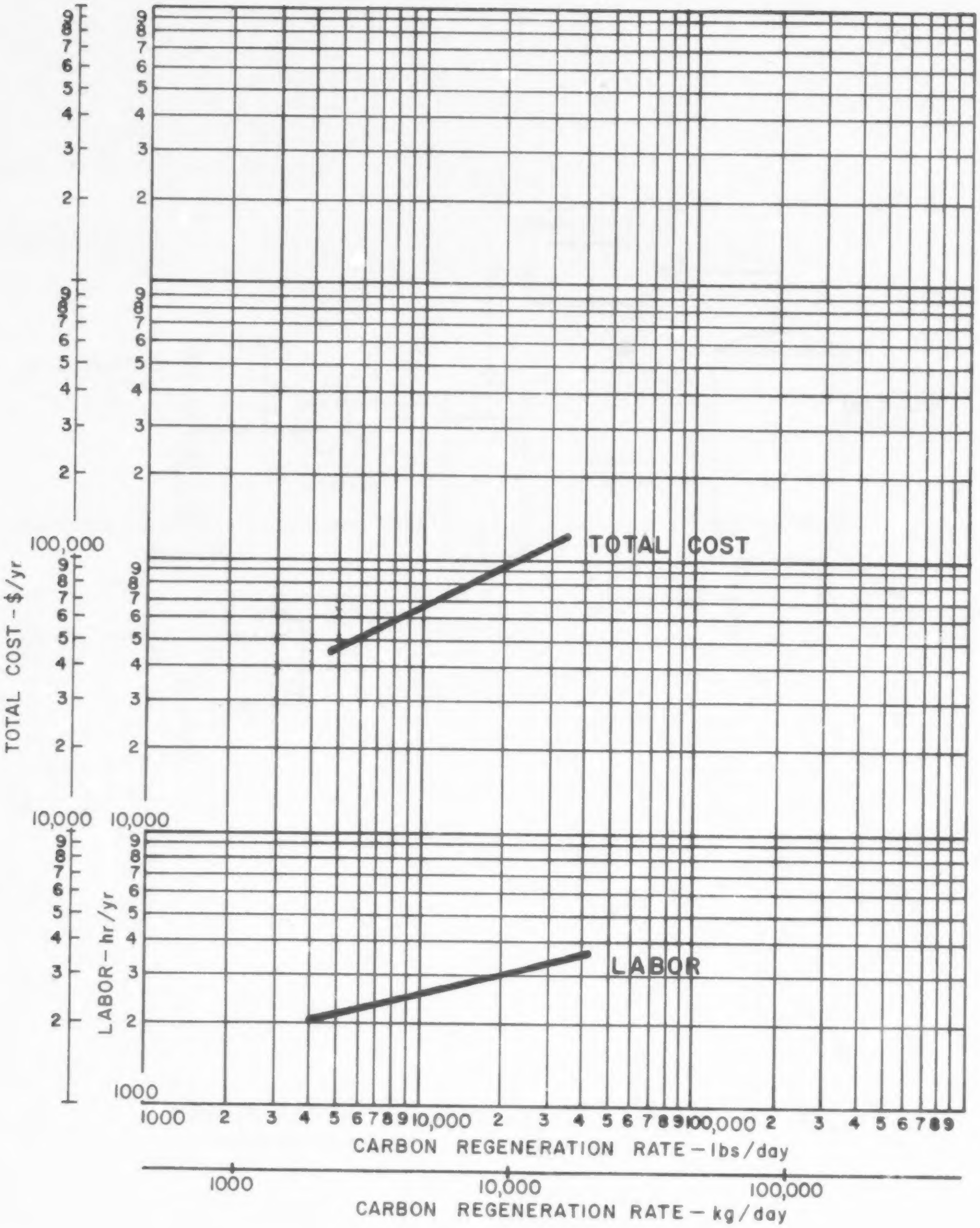


Figure 151. Operation and maintenance requirements for granular carbon regeneration, fluid bed process - labor and total cost.

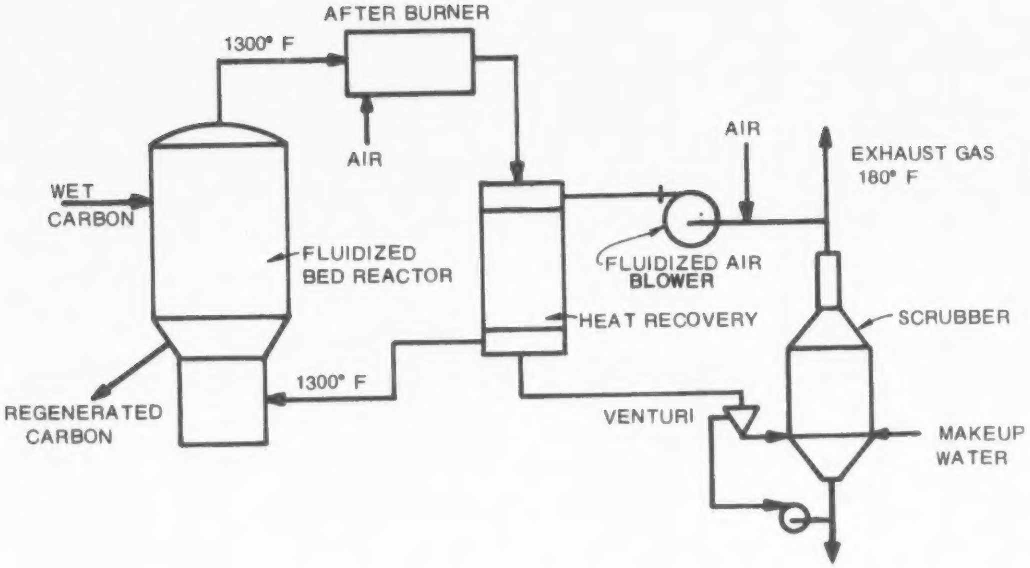

AFTER BURNER
1300° F
AIR
WET CARBON
FLUIDIZED BED REACTOR
REGENERATED CARBON
1300° F
HEAT RECOVERY
AIR
FLUIDIZED AIR BLOWER
EXHAUST GAS 180° F
SCRUBBER
VENTURI
MAKEUP WATER

Figure 152. Typical process diagram for fluidized bed powdered carbon regeneration system.

Table 131

Construction Cost for

Powdered Carbon Regeneration - Fluidized Bed Process

Cost Category	Regeneration Capacity (lb/day)				
	209	834	8,340	16,680	33,360
Manufactured Equipment	$250,000	$ 370,000	$ 1,000,000	$ 1,350,000	$ 2,400,000
Labor	188,000	267,500	700,000	945,000	1,600,000
Electrical	80,000	112,500	300,000	405,000	600,000
Housing	20,000	24,000	30,000	36,000	45,000
SUBTOTAL	538,000	774,000	2,030,000	2,736,000	4,645,000
Miscellaneous & Contingency	80,700	116,100	304,500	410,400	696,750
TOTAL	618,700	890,100	2,334,500	3,146,400	5,341,750

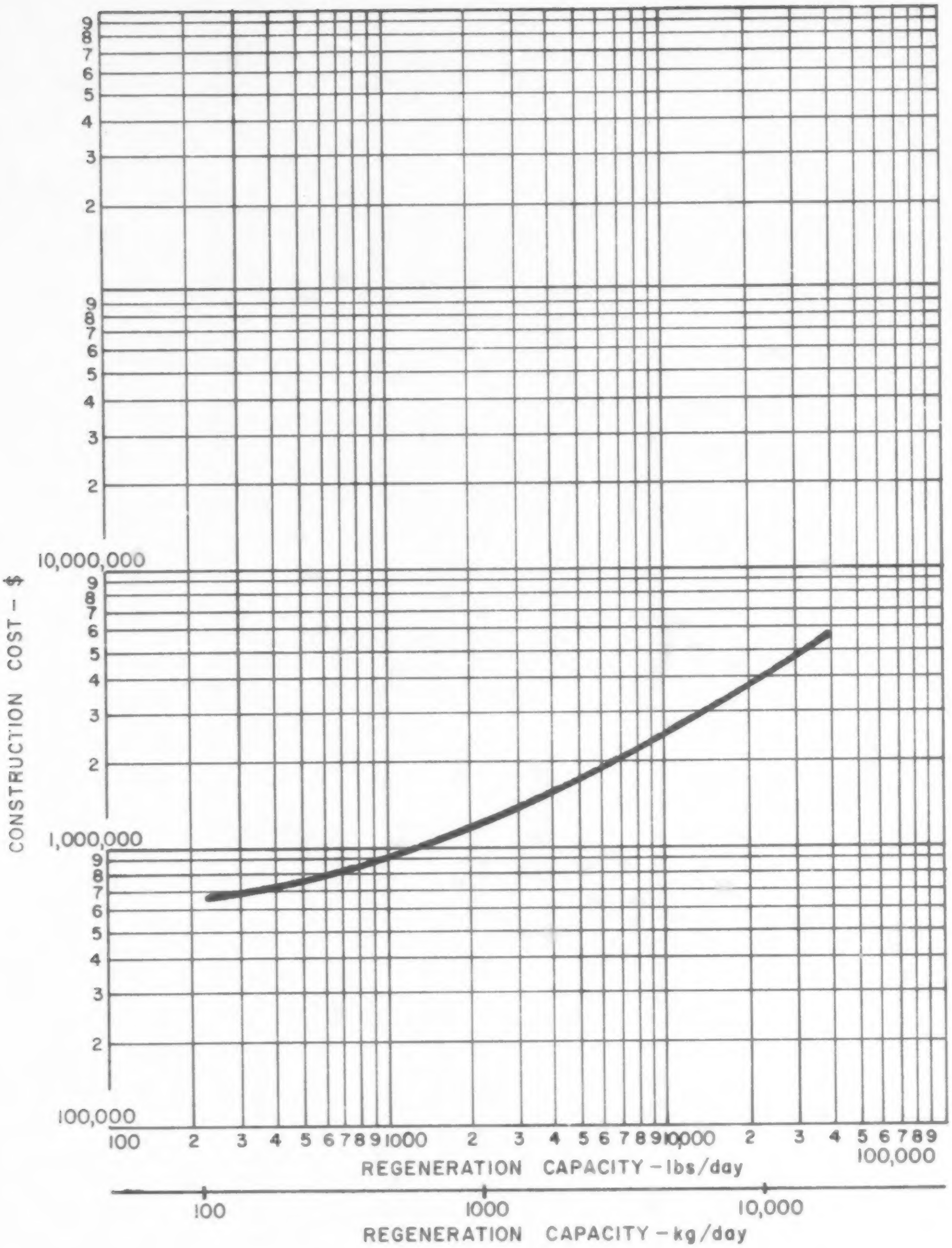


Figure 153. Construction cost for powdered carbon regeneration - fluidized bed process.

Operation and Maintenance Cost

Process electrical energy requirements were developed from manufacturers' listing of connected and operating horsepower for furnaces of various sizes. Continuous 24-hr/day, 365-day/year furnace operation was assumed in calculating energy and other operation and maintenance requirements.

Natural gas requirements were calculated from manufacturers' recommendations, assuming that the feed carbon had a moisture content of 73 to 78 percent. A natural gas heating value of 1,000 BTU/scf was used to determine energy requirements. Where an alternate fuel such as No. 2 fuel oil is utilized in place of natural gas, the appropriate number of gallons required can be calculated using a total fuel BTU value equal to that of natural gas.

Maintenance material costs were estimated from information furnished by equipment manufacturers. They are related to maintenance and repair of electrical drive and control machinery, replacement of FBF refractory materials, replacement of silica sand, and other general equipment maintenance items.

Labor requirements are related directly to operation of the equipment. Equipment manufacturers furnished information from which labor requirements were estimated.

Figures 154 and 155 present the operation and maintenance requirements, which are summarized in Table 132.

POWDERED CARBON REGENERATION - ATOMIZED SUSPENSION PROCESS

Construction Cost

One possible technique for reactivation of spent powdered activated carbon is the atomized suspension technique process, known as the AST process. To date only one installation is in service, a fact that contributes some uncertainty in the design criteria and construction cost estimates.

In the AST process, filter press dewatered, spent powdered carbon is mixed with water to form a slurry, then pumped through a spray nozzle where it is atomized with steam into the top zone of a three-zone AST reactor chamber. The reactor is normally 1 to 3 ft in diameter by 10 to 50 ft tall, depending on regeneration capacity. In the top zone the carbon is heated to about 1,200°F, evaporating the water and drying the carbon particles. In the middle zone, the adsorbate or contaminants on the powdered carbon are pyrolyzed, leaving a small residual char deposit in the original powdered carbon. This char is removed in the third zone, completing the reactivation. A flow schematic of the AST process is illustrated in Figure 156. Table 133 lists design criteria that were used to develop the cost estimate.

A cost curve was developed with data furnished by the manufacturer for units of 1,000 and 10,000 lb/day regeneration capacity. These represent the smallest and largest units economically feasible. The manufactured equipment cost includes the basic reactor, spent carbon slurry storage tank, furnace feed pump, regenerated carbon recovery equipment, and exhaust scrubbing

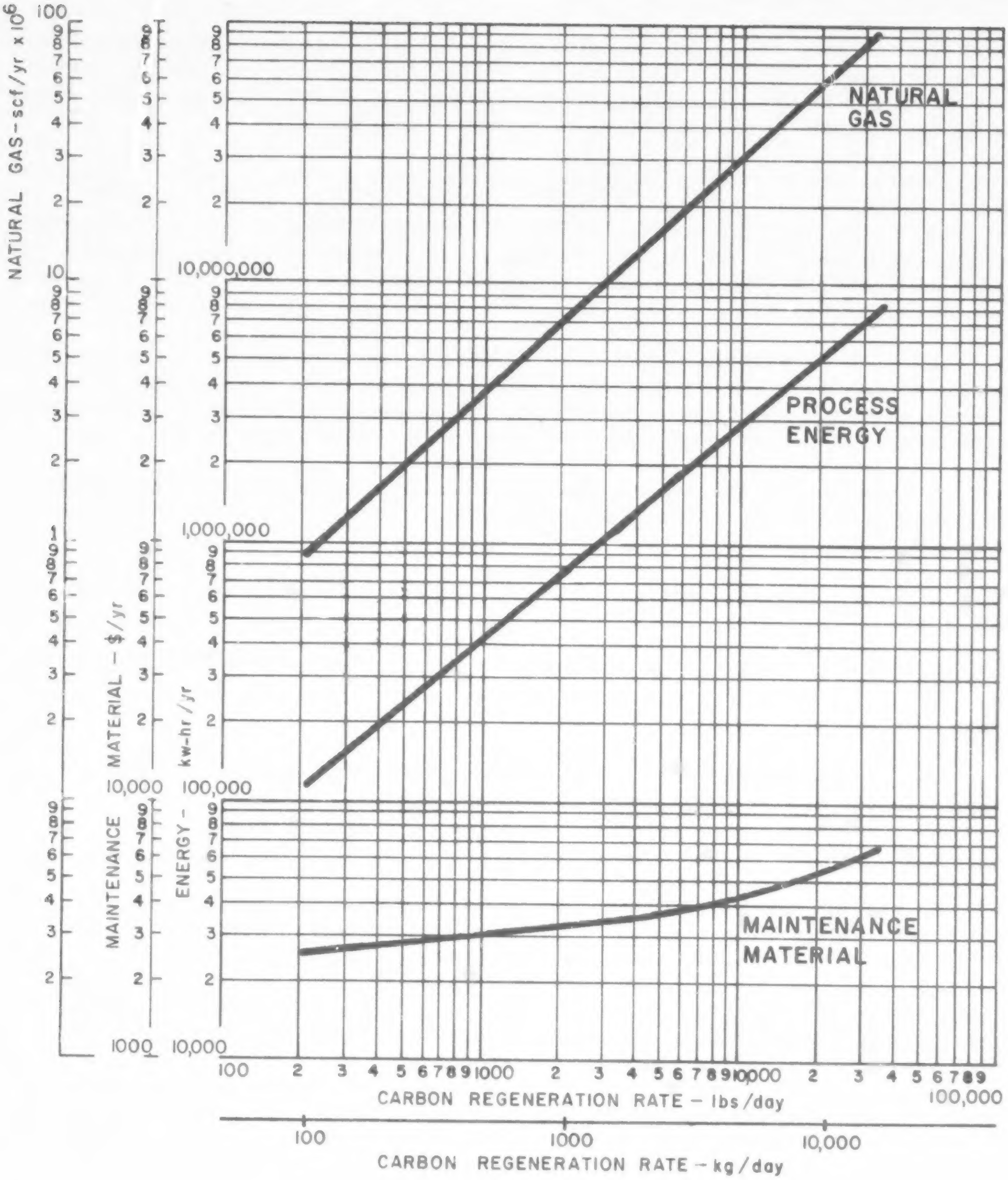


Figure 154. Operation and maintenance requirements for powdered carbon regeneration, fluidized bed process - natural gas, process energy, and maintenance material.

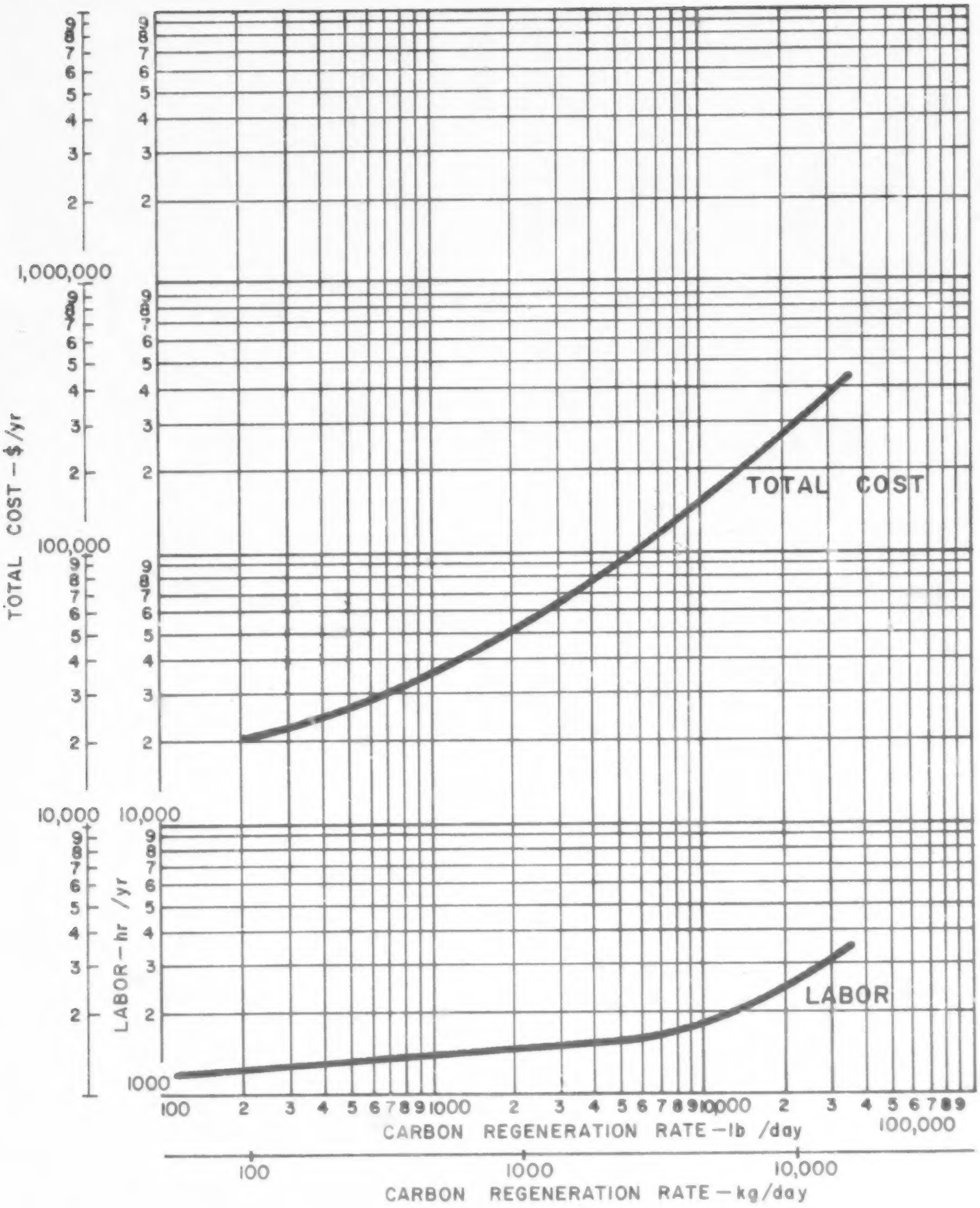


Figure 155. Operation and maintenance requirements for powdered carbon regeneration, fluidized bed process - labor and total cost.

Table 132

Operation and Maintenance Summary for

Powdered Carbon Regeneration - Fluidized Bed Process

Carbon Regeneration Rate (lb/day)	Process Energy (kw-hr/yr)	Natural Gas (scf/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
220	90,000	900,000	$ 2,500	1,150	$ 21,740
910	400,000	3,300,000	3,000	1,300	32,290
8,160	2,400,000	24,000,000	4,000	1,700	124,200
18,320	4,300,000	53,000,000	5,000	2,600	228,900
32,570	8,000,000	95,000,000	6,900	3,700	407,400

*Calculated using $0.03/kw-hr, $0.0013/ scf, and $10.00/hr of labor.

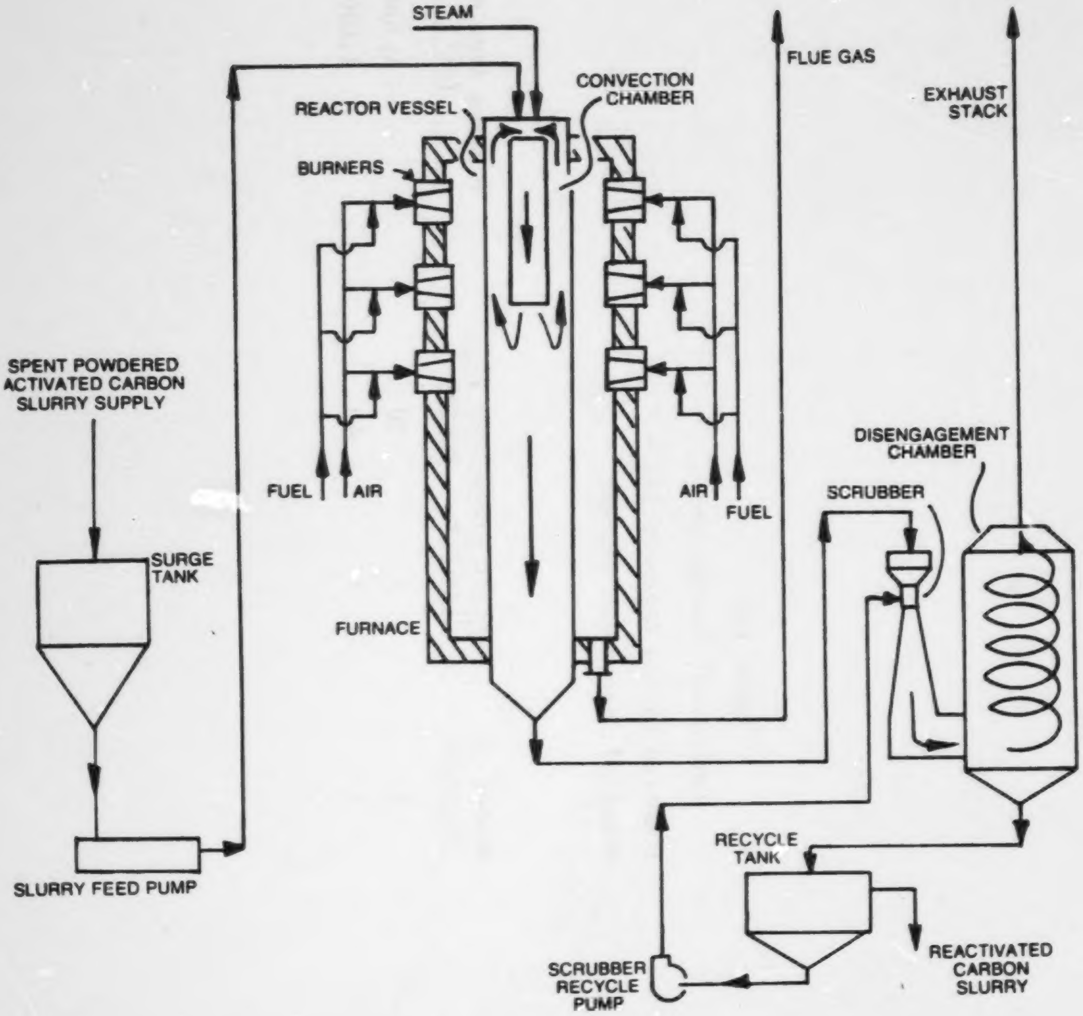

STEAM
CONVECTION CHAMBER
FLUE GAS
REACTOR VESSEL
EXHAUST STACK
BURNERS
SPENT POWDERED ACTIVATED CARBON SLURRY SUPPLY
DISENGAGEMENT CHAMBER
FUEL
AIR
AIR
FUEL
SCRUBBER
SURGE TANK
FURNACE
RECYCLE TANK
SLURRY FEED PUMP
REACTIVATED CARBON SLURRY
SCRUBBER RECYCLE PUMP

Figure 156. Schematic of the atomized suspension, powdered carbon regeneration system.

Table 133

Conceptual Design for

Powdered Carbon Regeneration - Atomized Suspension Process

Regeneration Capacity (lb/day	Number of Reactors	Reactor Dimensions (ft)		Process Area Requirement (ft^2)
		Diameter	Height	
1,000	1	1	20	1,200
10,000	1	3	40	1,600

facilities - all furnished and installed. Installation labor is estimated to be 25 to 30 percent of the total installed price. Housing is not included since the process could easily be located out-of-doors.

Table 134 and Figures 157 present estimated construction costs.

Operation and Maintenance Cost

Operation and maintenance costs were developed for AST process carbon regeneration facilities with capacities of 1,000 and 10,000 lb/day. These operating costs are from the manufacturers' estimate, using information obtained from a prototype production unit and from a single full-scale unit currently in service.

Process energy requirements are for process pumping and reactor air supply. Continuous 24-hr/day operation was assumed for 340 days/year, according to the manufacturer's recommendation, allowing 25 days of downtime for maintenance.

Natural gas requirements were calculated from the manufacturer's information; they assume that dewatered carbon is made up into a 30-percent dry solids slurry for injection into the reactor. A heating value of 1,000 BTU/scf was used to compute natural gas requirements. If an alternate fuel such as No. 2 fuel oil is to be utilized, the appropriate number of gallons required can be calculated using a total fuel BTU value equal to that of natural gas.

Maintenance material costs were estimated by the equipment manufacturer and relate to repair of electrically driven machinery, heating units, and controls and routine maintenance of the system. Labor requirements relate directly to operation of the equipment. No maintenance labor is included.

Operation and maintenance requirements are summarized in Table 135 and shown in Figures 158 and 159.

CHEMICAL SLUDGE PUMPING - UNTHICKENED SLUDGE

Construction Cost

Chemical sludge originating in clarifiers or recarbonation basins is relatively dilute and can be conveyed by gravity to the sludge pumping station wet well. Costs were developed for chemical sludge pumping stations having separate wet and dry wells. Variable speed, horizontal, centrifugal pumps were used for pumping of the dilute sludge, and one standby pump was included for each pumping station. Pipe and valves were sized for velocities of approximately 5 ft/second. Pumping station costs were estimated on the basis of a 12 ft depth and stairway access for stations with capacities greater than 100 gpm. Housing for electrical equipment and access to the dry well is located above the dry well, but the housing does not cover the entire dry well.

Construction costs are summarized in Table 136 and illustrated in Figure 160.

Table 134

Construction Cost for

Powdered Carbon Regeneration

Atomized Suspension Process

Cost Category	Regeneration Capacity (lb/day)	
	1,000	10,000
Manufactured Equipment*	$200,000	$ 1,500,000
Electrical & Instrumentation	30,000	225,000
Housing	54,000	104,000
SUBTOTAL	284,000	1,829,000
Miscellaneous & Contingency	42,600	274,350
TOTAL COST	326,600	2,103,350

* Includes installation labor.

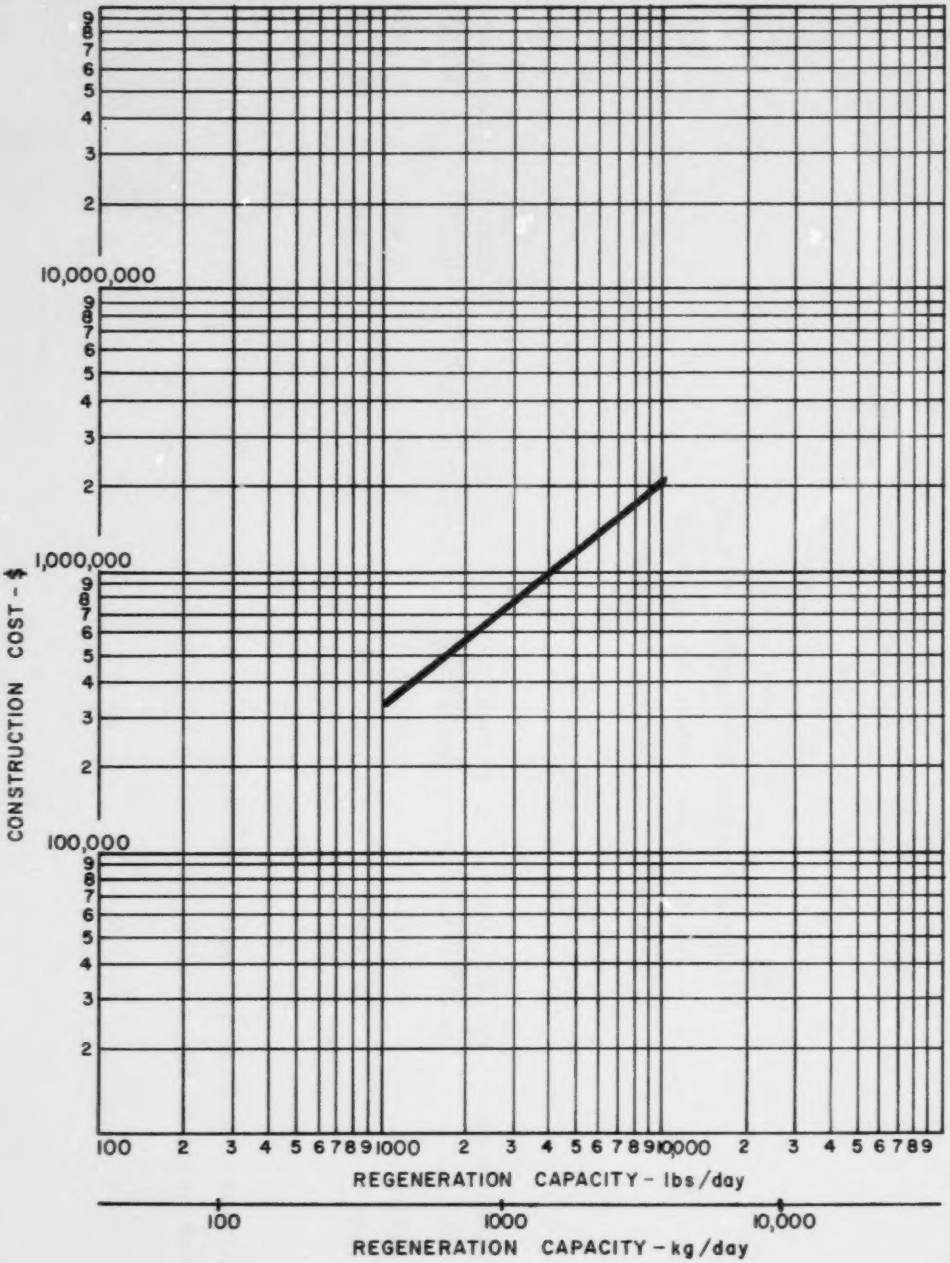


Figure 157. Construction cost for powdered carbon regeneration - atomized suspension process.

Table 135

Operation and Maintenance Summary for Powdered Carbon Regeneration - Atomized Suspension Process

Carbon Regenerated (lbs/day)$^+$	Process Energy (kw-hr/yr)	Natural Gas (scf/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1,000	46,670	6,000,000	2,000	1,020	21,400
10,000	445,000	55,000,000	3,000	1,520	103,050

$^+$340 days/year operation @ 3 shifts per day.

*Calculated using $0.03/kw-hr, $0.0013/scf and $10.00/hr of labor.

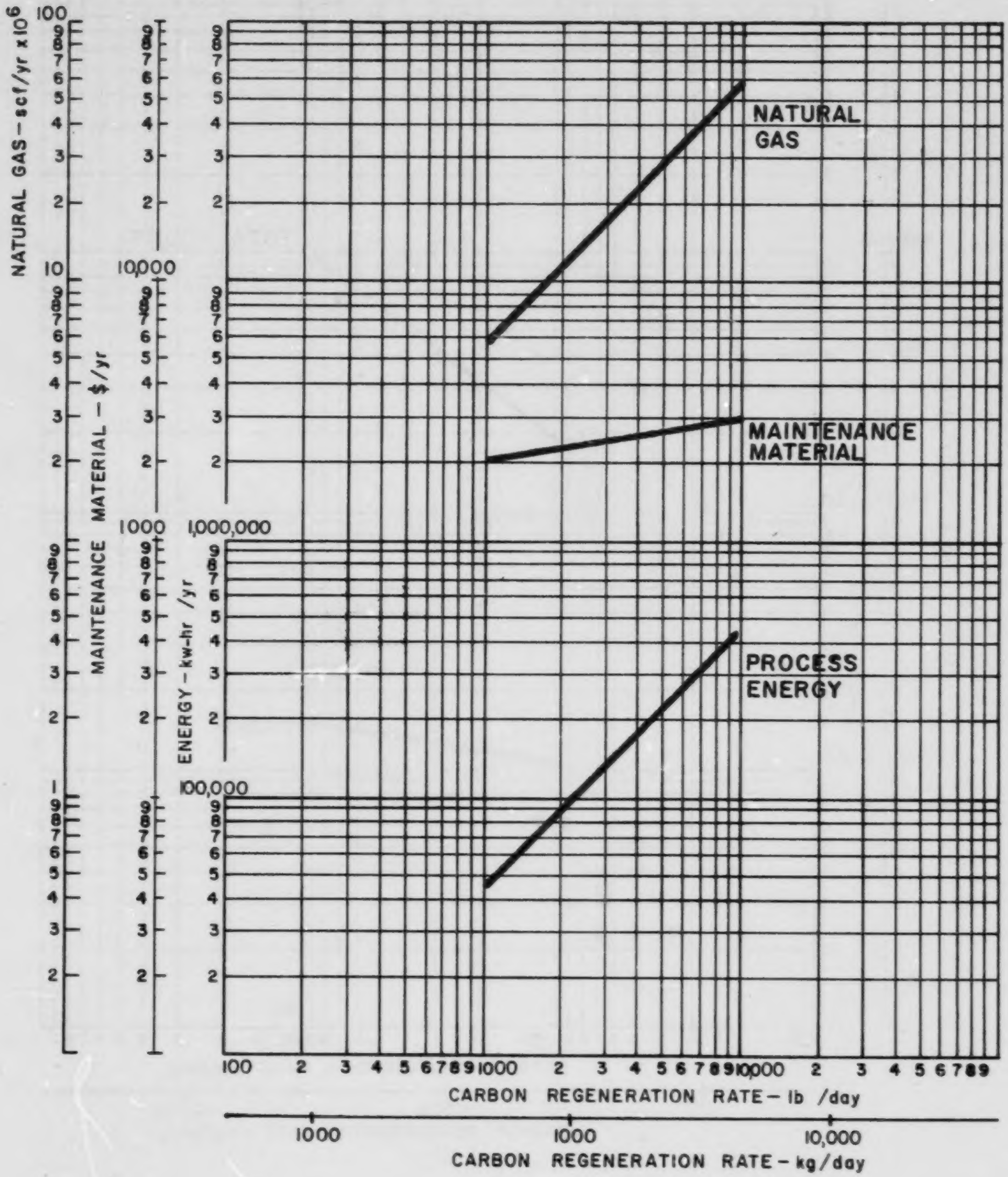


Figure 158. Operation and maintenance requirements for powdered carbon regeneration, atomized suspension process - natural gas, process energy, and maintenance material.

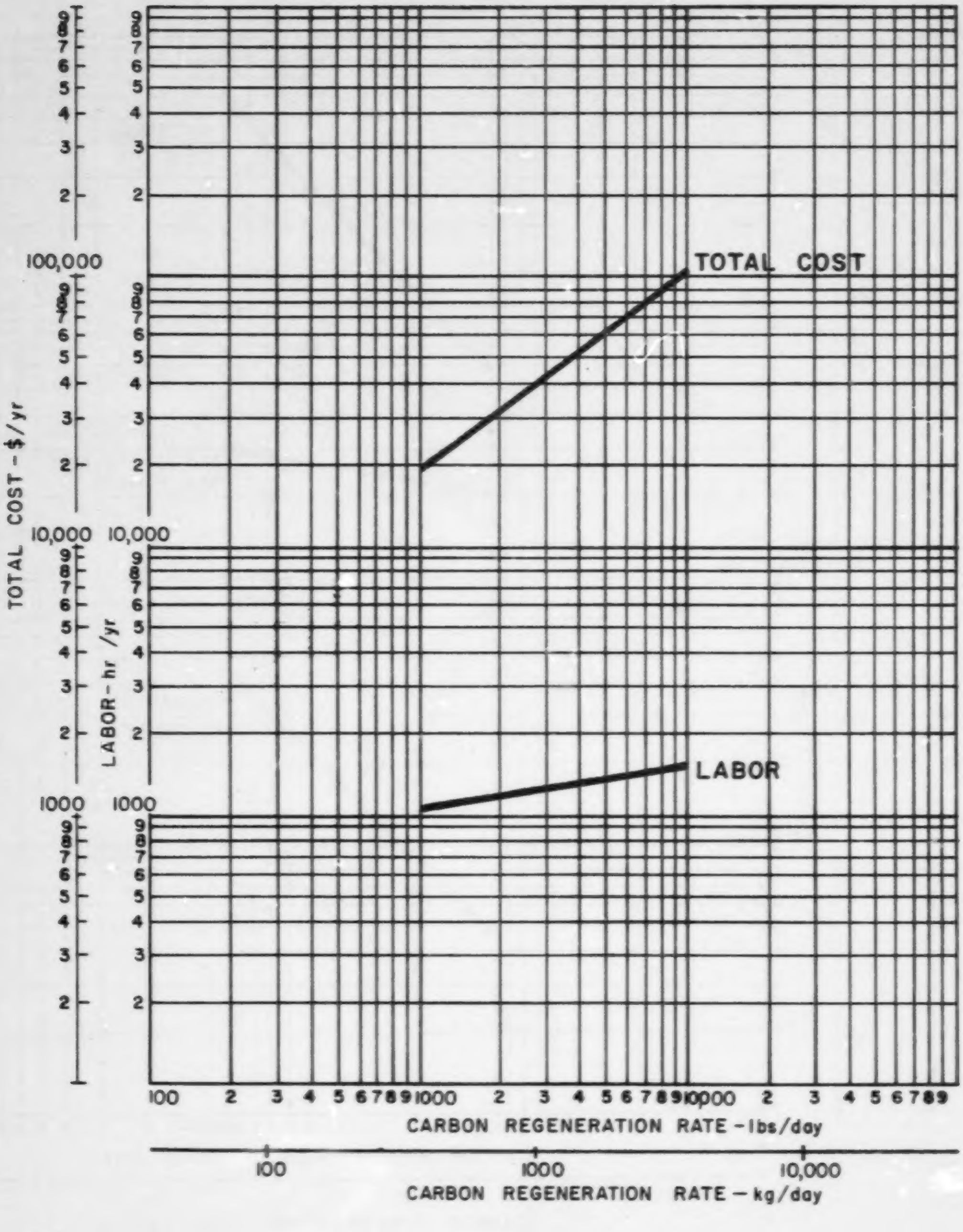


Figure 159. Operation and maintenance requirements for powdered carbon regeneration, atomized suspension process - labor and total cost.

Table 136

Construction Cost for

Chemical Sludge Pumping - Unthickened Sludge

Cost Category	Pumping Capacity (gpm)					
	20	100	500	1,000	5,000	10,000
Excavation and Sitework	$ 470	$ 600	$ 810	$ 970	$1,840	$ 2,220
Manufactured Equipment	4,370	6,230	8,210	10,390	23,320	38,440
Concrete	1,500	2,210	3,220	4,100	9,270	12,310
Steel	1,510	2,130	3,120	3,940	8,640	11,070
Labor	5,280	8,060	12,880	17,400	47,850	64,720
Pipe & Valves	2,560	4,570	10,870	18,190	42,810	79,060
Electrical & Instrumentation	6,290	7,390	7,880	9,380	10,380	12,510
Housing	5,880	5,880	5,880	8,100	8,100	11,700
SUBTOTAL	27,860	37,070	52,870	72,470	152,210	232,030
Miscellaneous & Contingency	4,180	5,560	7,930	10,870	22,830	34,810
TOTAL COST	32,040	42,630	60,800	83,340	175,040	266,840

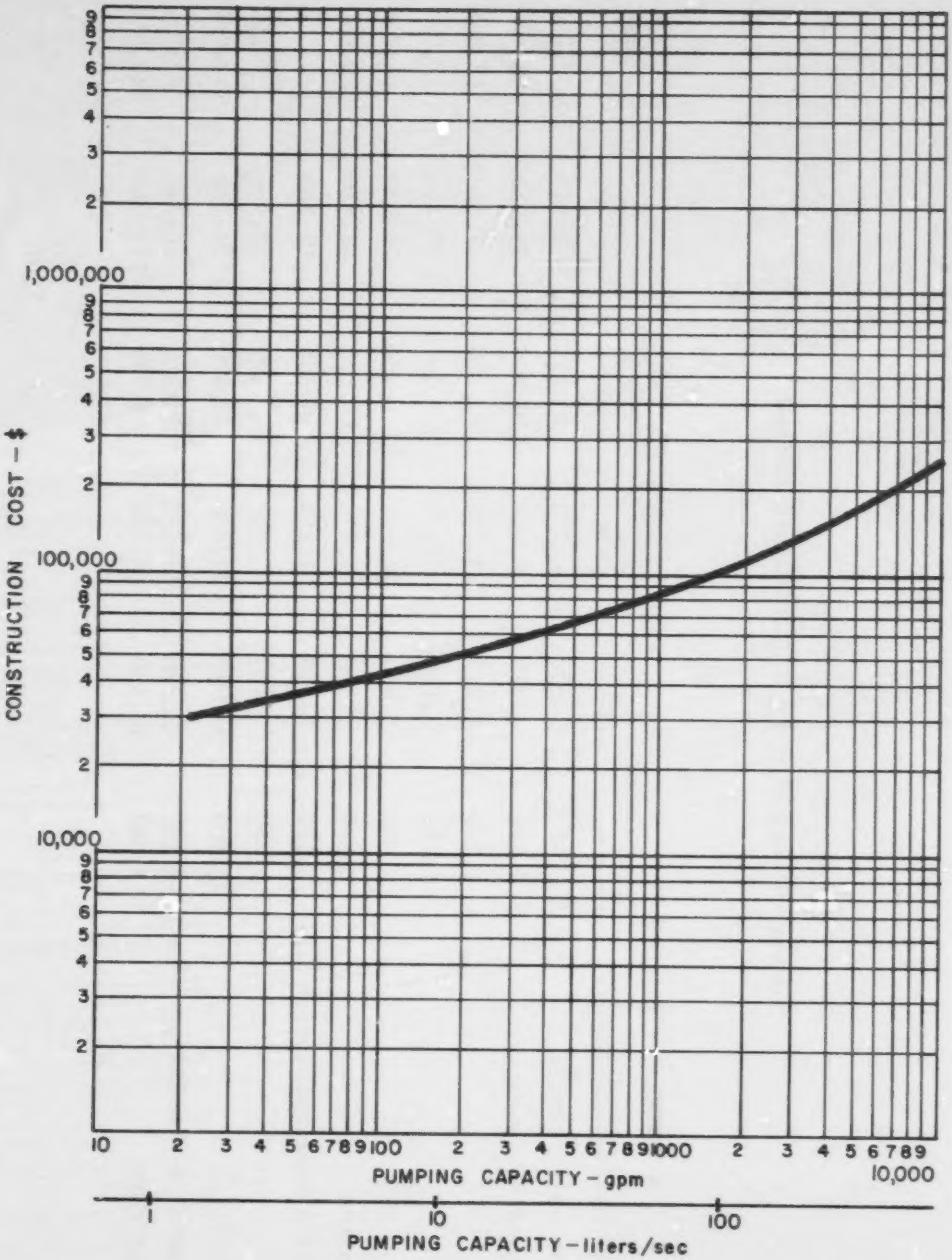


Figure 160. Construction cost for chemical sludge pumping - unthickened sludge.

Operation and Maintenance Cost

Process electrical energy costs are based on pumping a lime sludge against a total dynamic head of 30 ft. An overall motor-pump efficiency of 65 percent was utilized.

Maintenance material requirements are for periodic repair of the pumps, motors, and electrical control units. Labor requirements are for periodic checking of pumps and motors, and for periodic maintenance.

Figures 161 and 162 present operation and maintenance curves, and a summary of these requirements is presented in Table 137.

CHEMICAL SLUDGE PUMPING - THICKENED SLUDGE

Construction Cost

Thickened sludge from gravity sludge thickeners can be pumped using progressive cavity pumps. Costs were developed for such pumping stations, with the pumps drawing thickened sludge directly from the gravity thickener. The pumps were assumed to be located in a building used for other purposes, such as sludge dewatering or lime recalcination. The estimated costs include the pump and motors, required pipe and valving within the building, electrical equipment and instrumentation, and housing.

Construction costs are shown in Figures 163 and Table 138.

Operation and Maintenance Cost

Process electrical energy costs are based on pumping a thickened lime mud against a total dynamic head of 50 ft and manufacturers' estimates of connected horsepower.

Maintenance material requirements are for periodic repair of the pumps, motors, and electrical control units. Labor requirements are for periodic checking of the pumping equipment, and for periodic maintenance.

Figures 164 and 165 present operation and maintenance curves, and a summary of the operation and maintenance requirements is presented in Table 139.

GRAVITY SLUDGE THICKENERS

Construction Cost

Gravity sludge thickeners are often used before dewatering by centrifuge, vacuum filter, filter press, or other methods. Gravity thickeners are similar to circular clarifiers, although the thickener mechanism is somewhat different.

Construction costs consist of the cost of the thickener mechanism and its installation, and the cost of a reinforced concrete structure. The cost of the reinforced concrete structure was calculated using a 12-ft side wall

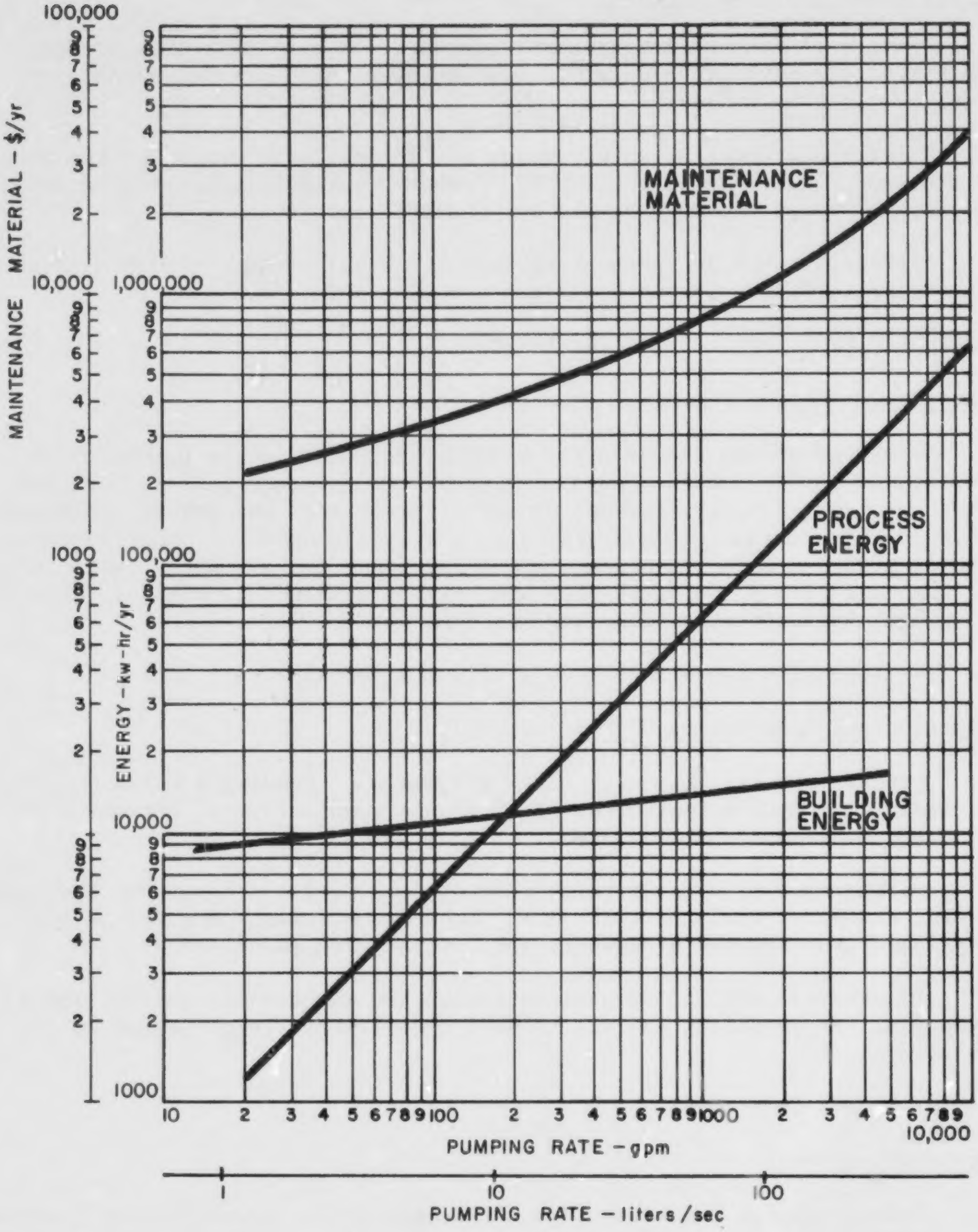


Figure 161. Operation and maintenance requirements for chemical sludge pumping - unthickened sludge - building energy, process energy, and maintenance material.

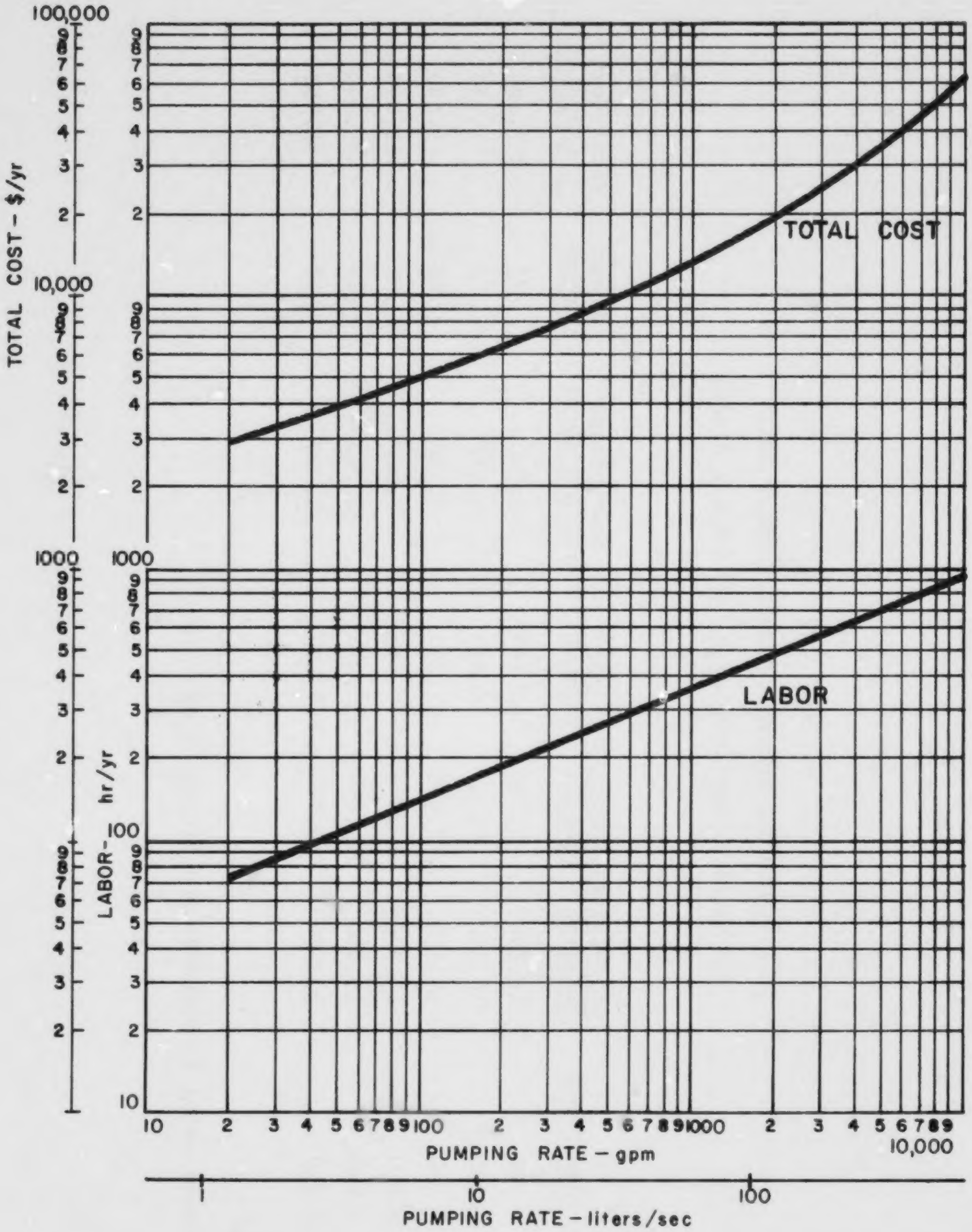


Figure 162. Operation and maintenance requirements for chemical sludge sludge pumping - unthickened sludge - labor and total cost.

Table 137

Operation and Maintenance Summary for

Chemical Sludge Pumping - Unthickened Sludge

Pumping Rate (gpm)	Electrical Energy (kw-hr/yr) Building	Process	Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost * ($/yr)
20	10,260	1,280	11,540	$ 2,260	75	$ 3,360
100	10,260	6,400	16,660	3,430	140	5,330
500	10,260	31,940	42,200	5,580	280	9,650
1,000	15,390	63,970	79,360	8,670	380	14,850
5,000	15,390	319,860	335,250	22,740	710	39,900
10,000	20,520	639,710	660,230	39,740	940	68,950

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

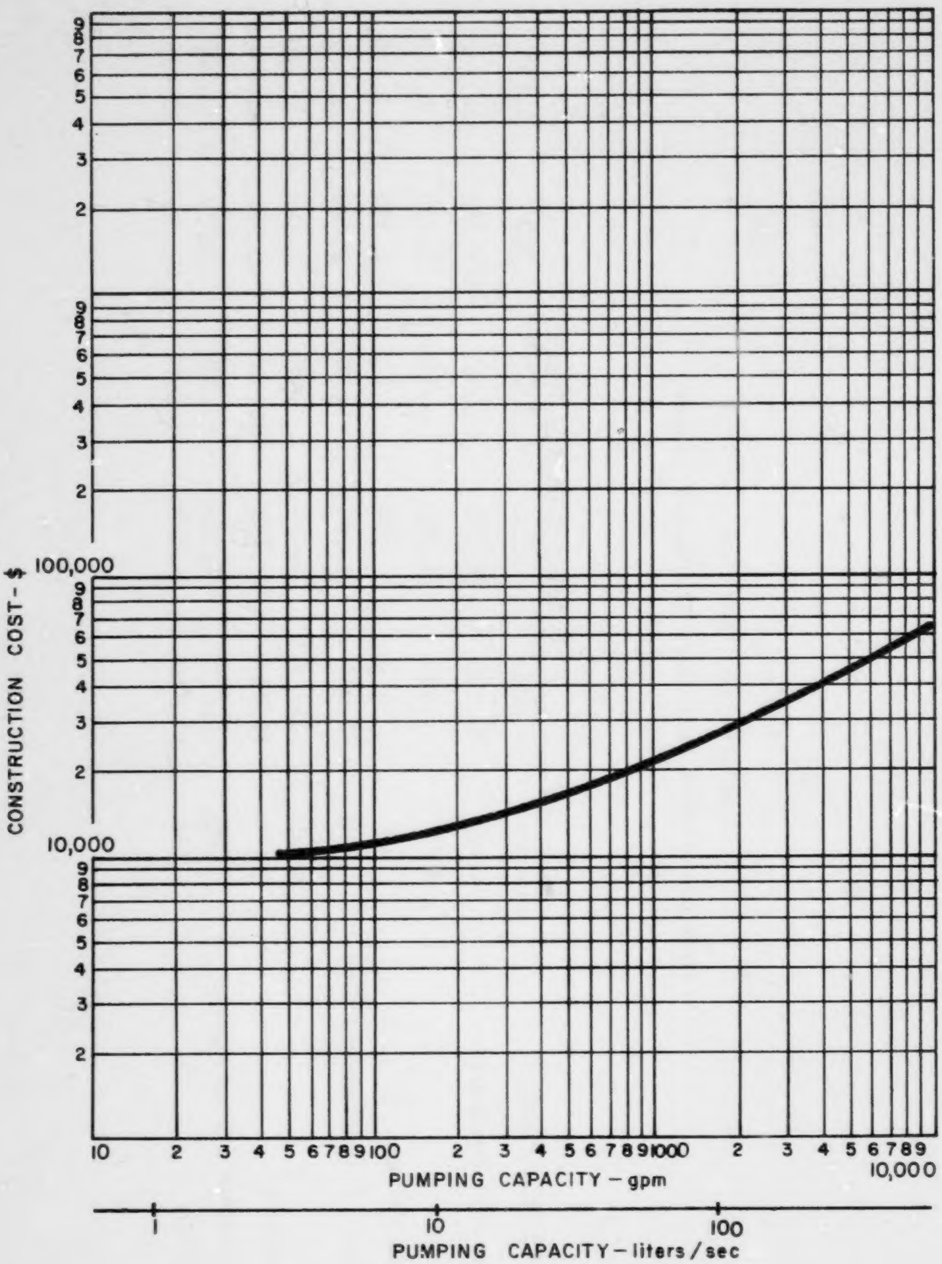


Figure 163. Construction cost for chemical sludge pumping - thickened sludge.

Table 138

Construction Cost for
Chemical Sludge Pumping - Thickened Sludge

Cost Category	Pumping Capacity (gpm)					
	5	25	50	200	500	1,250
Manufactured Equipment	$4,130	$7,330	$8,130	$20,080	$28,050	$44,630
Labor	810	1,280	1,550	3,850	5,750	8,970
Pipe and Valves	390	470	630	920	1,320	1,520
Electrical & Instrumentation	940	1,020	1,180	1,770	2,100	2,370
Housing	1,700	1,700	1,700	3,400	3,400	3,400
SUBTOTAL	7,970	11,800	13,190	30,020	40,620	60,890
Miscellaneous & Contingency	1,200	1,770	1,980	4,500	6,090	9,130
TOTAL	9,170	13,570	15,170	34,520	46,710	70,020

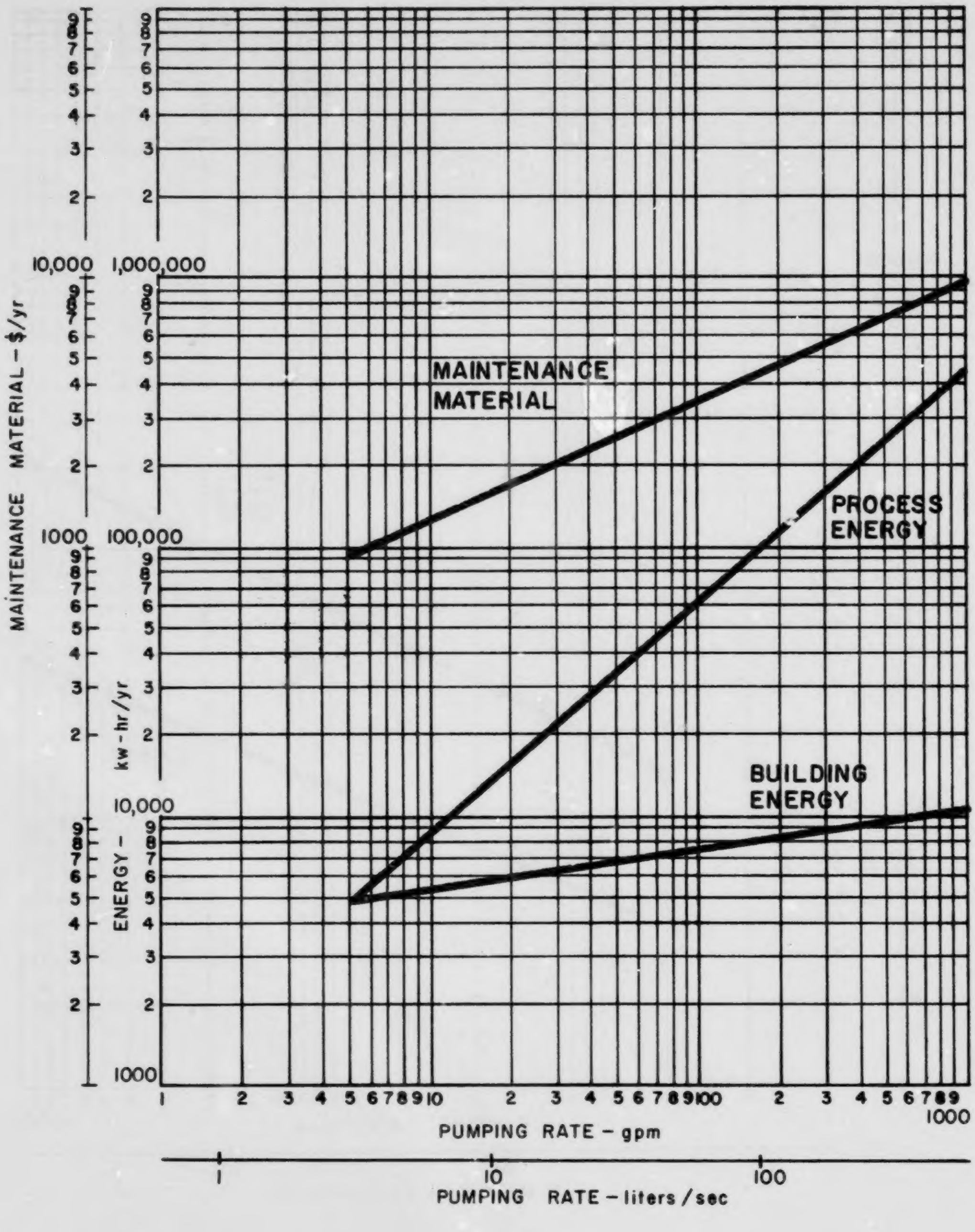


Figure 164. Operation and maintenance requirements for chemical sludge pumping, thickened sludge - building energy, process energy, and maintenance material.

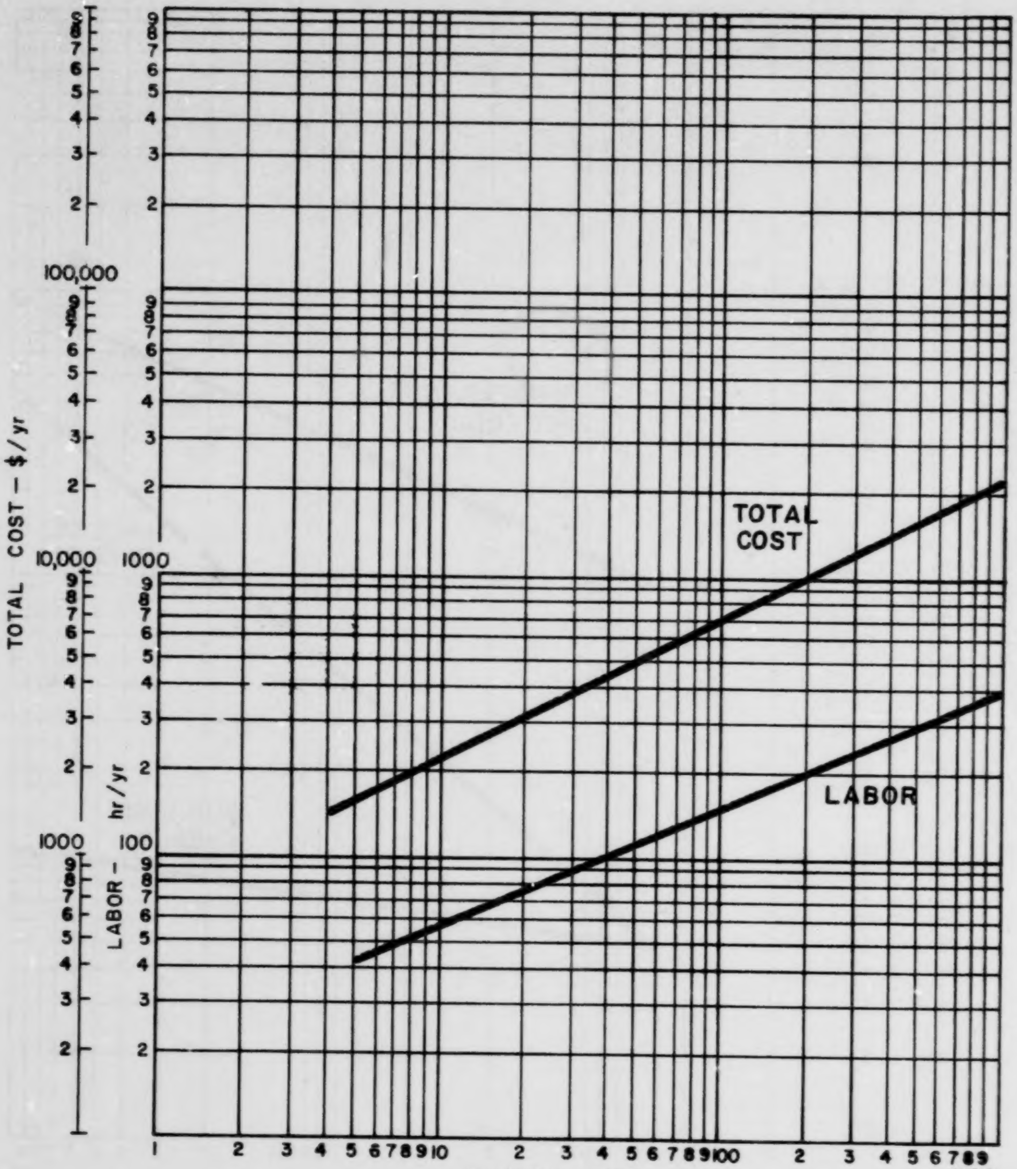


Figure 165. Operation and maintenance requirements for chemical sludge pumping, thickened sludge - labor and total cost.

Table 139

Operation and Maintenance Summary for Chemical Sludge Pumping - Thickened Sludge

Pumping Rate (gpm)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
5	5,130	4,900	10,030	$1,090	50	$1,890
25	5,130	19,600	24,730	1,760	75	3,250
50	5,130	32,660	37,790	1,990	105	4,170
200	10,260	65,320	75,580	4,550	190	8,720
500	10,260	261,300	271,560	6,290	280	17,240
1,250	10,260	424,610	434,870	9,700	400	26,750

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

depth. Concrete effluent troughs were utilized for all sizes, with the weir baffle located on the inboard side of the concrete trough. All mechanisms were assumed to be supported by the center column and include a steel bridge from the edge of the thickener to the center column.

Construction costs are presented in Table 140 and Figure 166.

Operation and Maintenance Cost

Process energy requirements were calculated for lime, alum, and ferric sludges; they are only for driving the thickener mechanism. Energy requirements for sludge pumping are not included, as a separate curve is provided for thickened sludge pumping.

Maintenance material costs and labor requirements are for repair and normal maintenance of the thickener drive mechanism and the weirs.

Figures 167 and 168 present curves for operation and maintenance requirements, and Table 141 summarizes these requirements.

VACUUM FILTERS

Construction Cost

Vacuum filters have had extensive application to dewatering of wastewater treatment sludges, but they have only recently been applied to the dewatering of water plant sludges. With proper sludge conditioning, even difficult to dewater sludges such as alum sludge can be successfully processed with vacuum filters.

Construction costs were developed for single and multiple installations capable of handling sludge volumes ranging from 3,600 to 720,000 gpd. Conceptual design information for these installations is shown in Table 142. Equipment was selected assuming a feed sludge concentration of 1 percent solids, a minimum sludge cake solids concentration of 20 percent, and continuous 24-hr/day operation. The costs include the vacuum drum filter, vacuum and filtrate pump assemblies, precast pump and storage tanks, belt conveyor, interconnecting piping, electrical controls and housing. Figure 169 illustrates a typical installation.

Table 143 presents construction costs for vacuum filter installations with filter areas ranging from 9.4 to 1,320 ft^2. Figure 170 illustrates the construction costs for vacuum filters presented as a function of filter surface area.

Operation and Maintenance Cost

Electrical energy requirements are for both building and process energy. Process energy requirements were based on manufacturers' design values of total connected horsepower for the drum drive, discharge roller, vacuum and filtrate pumps, precoat pump, tank agitators, and belt conveyor. A filter loading of approximately 1.7 lb of dry solids/hr per ft^2 with a

Table 140

Construction Cost for Gravity Sludge Thickeners

	Surface Area (ft^2) and Diameter (ft)						
Cost Category	314 ft^2, 20 ft	1,256 ft^2, 40 ft	2,827 ft^2, 60 ft	5,026 ft^2, 80 ft	7,854 ft^2, 100 ft	12,271 ft^2, 125 ft	17,671 ft^2, 150 ft
Excavation & Sitework	$980	$2,120	$3,430	$4,900	$6,530	$8,800	$11,320
Manufactured Equipment	26,250	40,000	52,500	61,250	63,750	73,000	101,000
Concrete	3,110	6,730	10,850	15,480	20,610	27,740	35,600
Steel	4,460	9,430	14,880	20,840	27,290	36,060	45,600
Labor	10,080	18,790	27,840	36,840	45,420	57,780	73,770
Electrical & Instrumentation	1,420	1,420	1,460	1,460	1,510	1,550	1,730
SUBTOTAL	46,300	78,490	110,960	140,770	165,110	204,930	269,020
Miscellaneous & Contingency	6,950	11,770	16,640	21,120	24,770	30,740	40,350
TOTAL	53,250	90,260	127,600	161,890	189,880	235,670	309,370

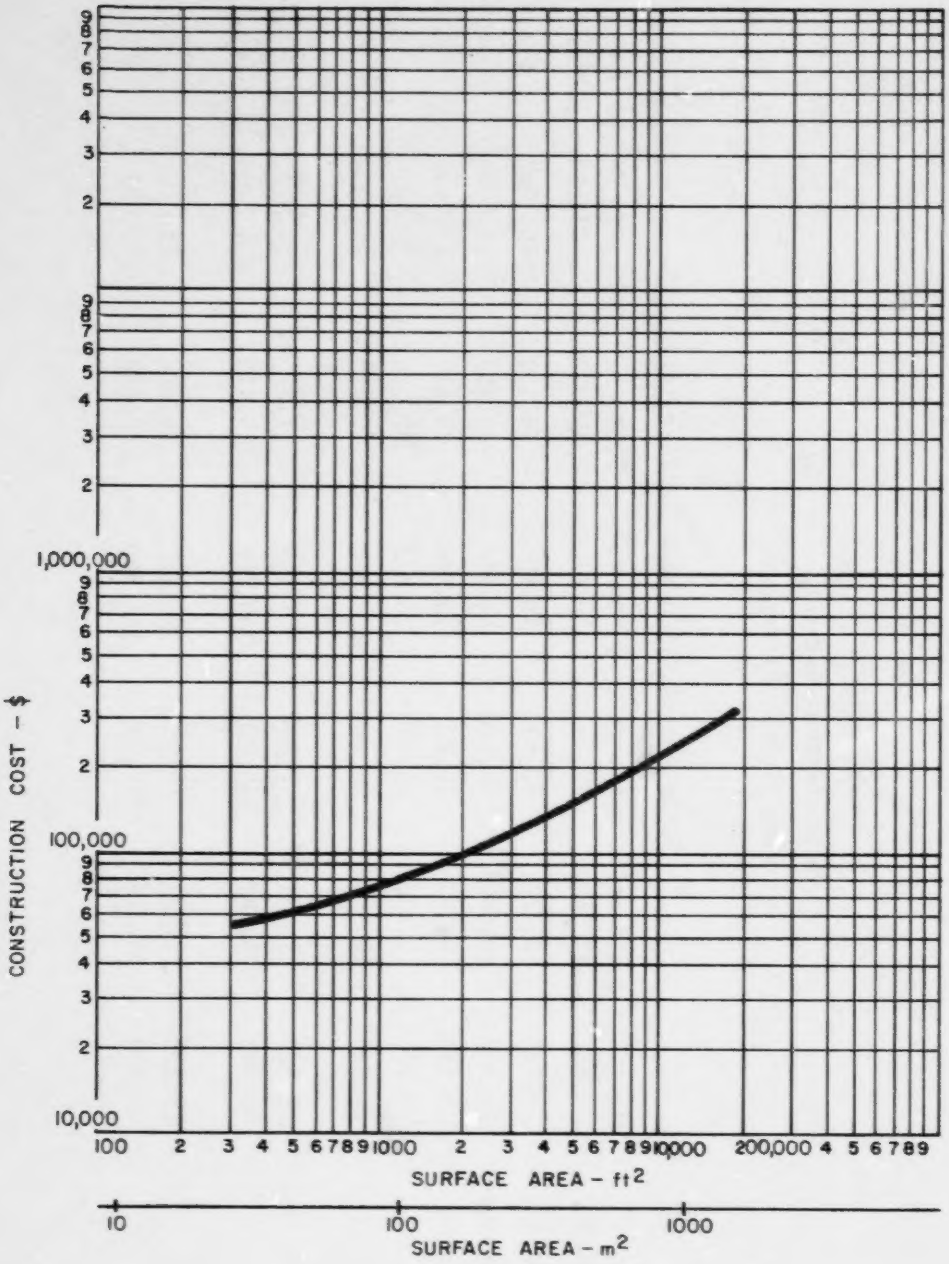


Figure 166. Construction Cost for gravity sludge thickeners.

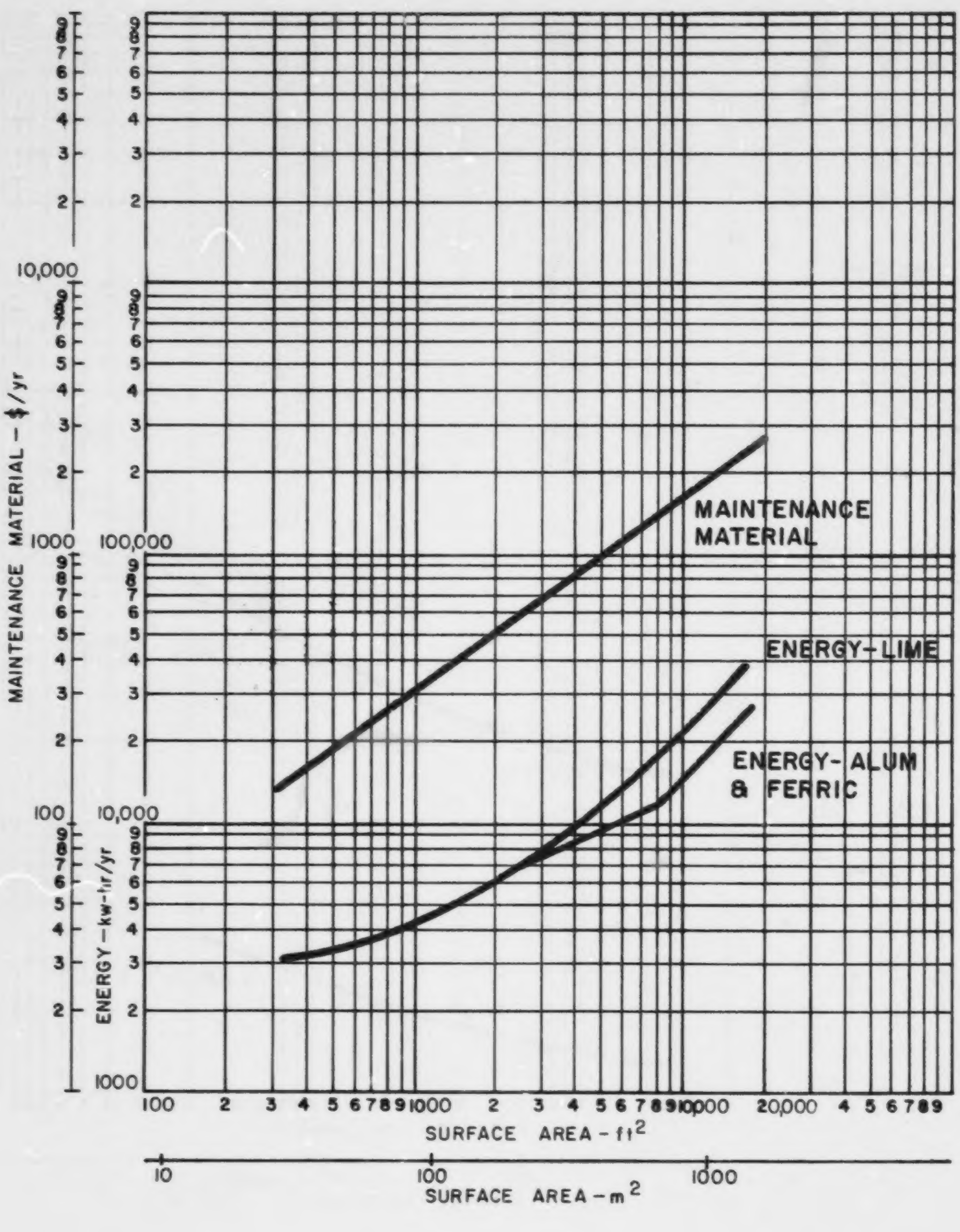


Figure 167. Operation and maintenance requirements for gravity sludge thickeners - process energy and maintenance material.

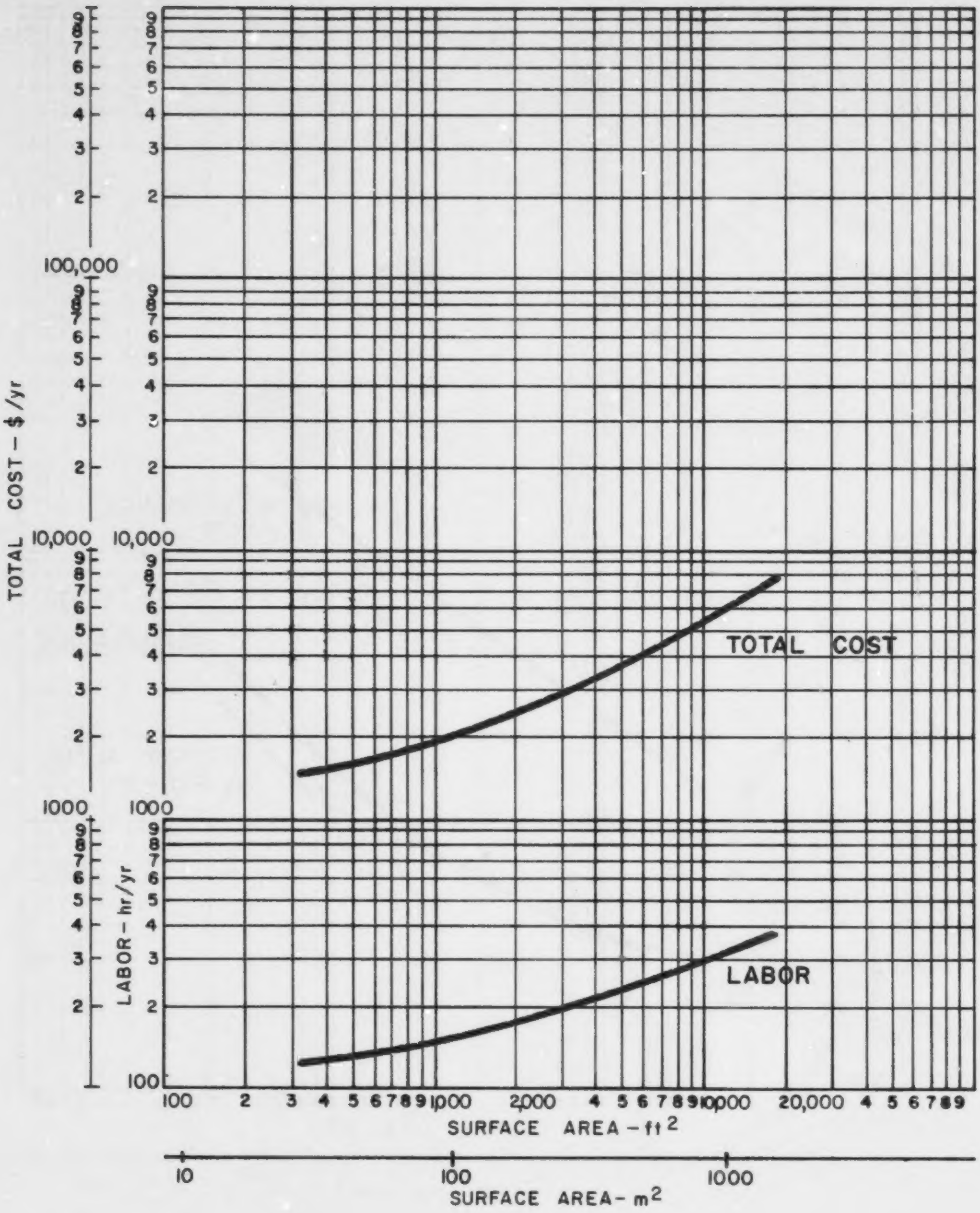


Figure 168. Operation and maintenance requirements for gravity sludge thickeners - labor and total cost.

Table 141

Operation and Maintenance Summary for Gravity Sludge Thickeners

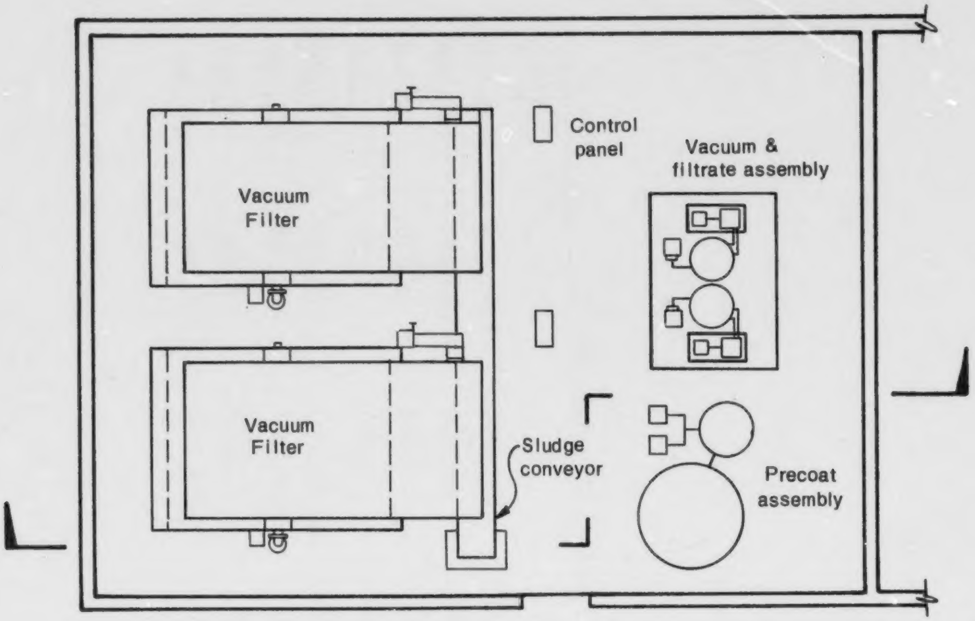
Surface Area (ft^2)	Diameter (ft)	Energy (kw-hr/yr)		Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)	
		Alum & Ferric Sludge	Lime Sludge			Alum & Ferric Sludge	Lime Sludge
314	20	3,270	3,270	$140	125	$1,490	$1,490
1,256	40	4,900	4,900	350	160	2,100	2,100
2,827	60	6,540	7,520	470	200	2,670	2,700
5,026	80	10,460	12,420	1,000	230	3,610	3,670
7,854	100	12,420	18,950	1,400	280	4,570	4,770
12,271	125	18,300	29,080	1,850	310	5,500	5,820
17,671	150	28,750	39,210	2,400	390	7,160	7,480

*Calculated using $0.03/kw-hr and $10.00/ hr of labor.

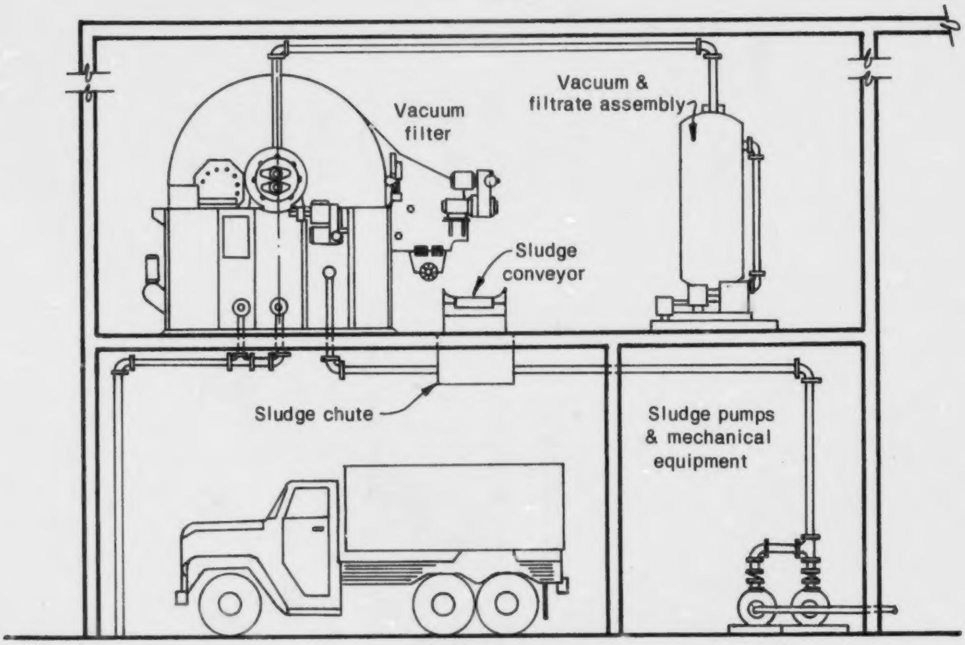
Table 142
Conceptual Design for Vacuum Filters

Total Installed Machine Capacity (gpd)*	Total Filter Surface Area (ft^2)	Number of Machines	Housing Requirements (ft^2)
3,600	9.4	1	1,280
18,000	38	1	1,350
36,000	71	1	1,480
360,000	628	2	2,150
720,000	1,320	3	3,625

*Based on average loading of 1.7 lb of dry solids/hr per ft^2 and a feed sludge flow of 1 percent solids concentration.


Vacuum Filter
Vacuum Filter
Control panel
Vacuum & filtrate assembly
Sludge conveyor
Precoat assembly

PLAN VIEW


Vacuum filter
Vacuum & filtrate assembly
Sludge conveyor
Sludge chute
Sludge pumps & mechanical equipment

ELEVATION VIEW

Figure 169. Typical vacuum filter installation.

Table 143

Construction Cost for
Vacuum Filters

Cost Category	Total Filter Area (ft^2) 9.4	38	71	628	1,320
Manufactured Equipment	$ 65,600	$73,500	$85,700	$262,000	$445,000
Labor	22,500	26,000	29,500	118,000	198,000
Pipe and Valves	3,500	3,500	3,800	5,300	8,500
Electrical & Instrumentation	2,500	2,500	2,800	7,500	23,200
Housing	52,800	59,400	63,600	81,700	127,000
SUBTOTAL	146,900	164,900	185,400	474,500	801,700
Miscellaneous & Contingency	22,040	24,740	27,800	71,180	120,260
TOTAL COST	168,940	189,640	213,200	545,680	921,960

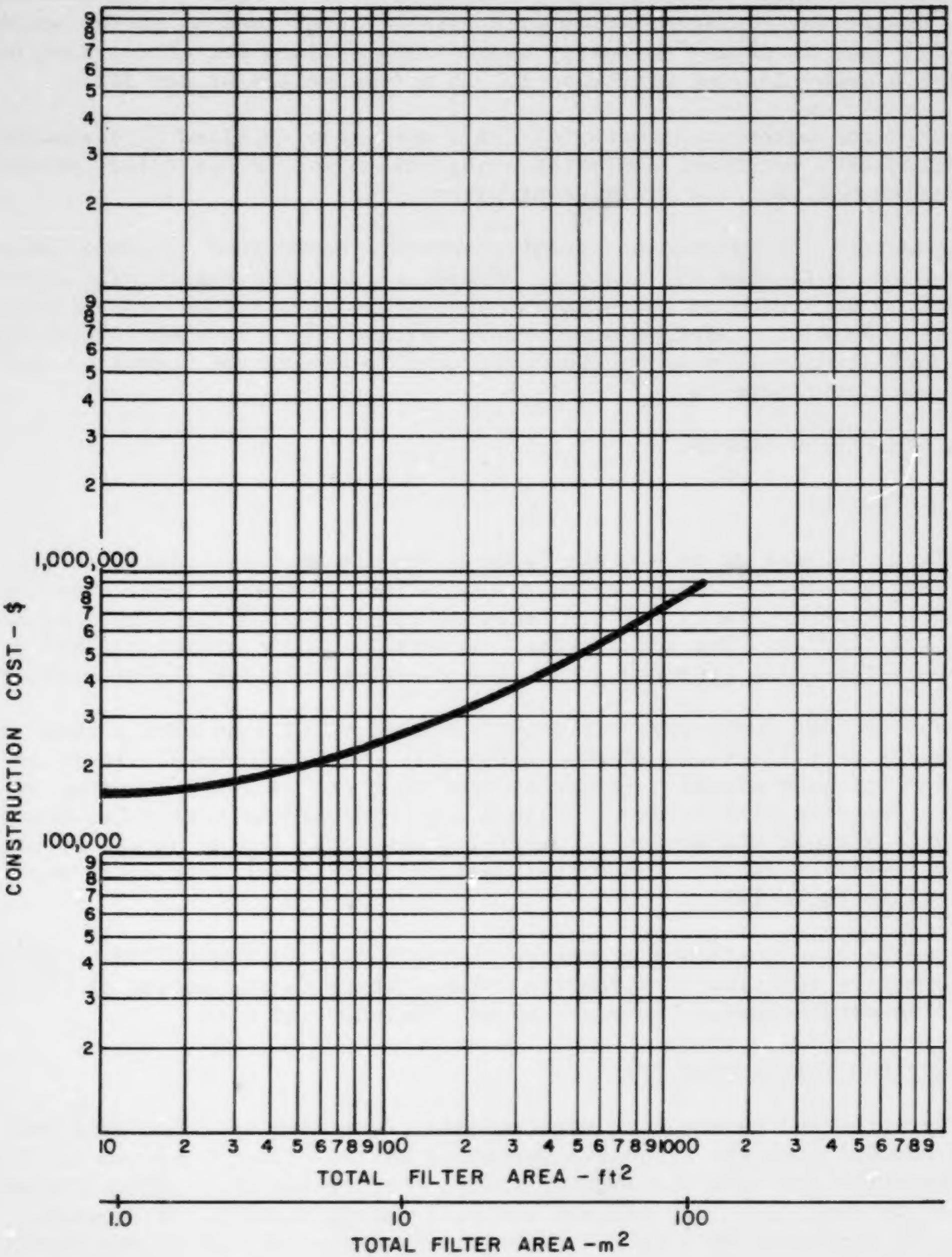


Figure 170. Construction cost for vacuum filters.

minimum cake solids concentration of 20 percent was used in computing energy requirements. These conditions are characteristic of alum sludge dewatering. Sludge dewatering characteristics will affect filter loading rates, which in turn will have an impact on energy usage. Appropriate correction must be made for a lower loading rate than 1.7 lb of dry solids/hr per ft^2.

Labor and maintenance material costs were also obtained from equipment suppliers; they represent estimated annual requirements for filter operation and maintenance, and for replacement parts.

Operation and maintenance requirements are summarized in Table 144 and illustrated in Figures 171 and 172. Operation and maintenance requirements vary widely depending on hours/day of operation, feed sludge concentration, and filter loading. Appropriate corrections should be made when conditions vary significantly from those that were used to derive the operation and maintenance requirements.

SLUDGE DEWATERING LAGOONS

Construction Cost

Sludge dewatering or storage lagoons are used at many plants to receive, store, and partially dewater waste sludge before further treatment or ultimate disposal. In some plants, filter backwash water is also discharged to a lagoon for clarification and storage. Generally, when sufficient land area is available, lagooning represents the lowest cost system for sludge dewatering.

Construction costs were estimated for unlined lagoons with a 10-ft water depth and a 2-ft freeboard depth. Dikes were assumed to have a 10-ft crest width and 3:1 side slopes. It was assumed that the excavation volume is equal to the dike fill volume. Lagoons were designed with an inlet structure that would prevent disturbance of settling material, and an outlet structure to skim clarified water. Conceptual designs used to estimate costs are presented in Table 145.

Construction costs are presented in Table 146 and Figure 173. The costs are shown as a function of effective volume, which is the volume of the lagoon minus freeboard volume. The costs do not include land cost.

Operation and Maintenance Cost

Operation and maintenance requirements are primarily associated with sludge removal from the lagoons. Depending on the climate and the ability of water to percolate from the lagoon, sludge can thicken to a solids content of 15 to 40 percent (17 to 20 percent average) during 6 months of storage. Removal is generally done with a front-end loader or with dragline dredging. Dredging is used to allow further dewatering by air drying on the lagoon periphery. After air drying, the concentrated sludge is removed by a front-end loader. The costs and requirements presented are for a combination of these approaches. Sludge was assumed to be removed from a lagoon, on the average of once every 2 years, and hauled in dump trucks to within 1 mile of the lagoons. If a further haul distance is required, curves provided elsewhere in this report for sludge hauling should be utilized.

Table 144

Operation and Maintenance Summary for Vacuum Filters

Total Filter Area (ft^2)	Sludge Flow Rate (gpd)*	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost+ ($/yr)
		Building	Process	Total			
9.4	3,600	131,330	94,600	225,930	$3,000	800	$17,780
38	18,000	138,500	126,140	264,640	7,800	1,050	26,240
71	36,000	151,850	197,100	348,950	11,000	1,900	40,470
628	360,000	220,600	1,088,000	1,308,600	50,000	6,500	154,260
1,320	720,000	372,000	2,365,000	2,737,000	82,000	11,000	274,110

*Based on average loading at 1.7 lb/day per ft^2 of dry solids and a feed sludge flow at 1 percent solids concentration.

+Calculated using $0.03/kw-hr and $10.00/hr of labor.

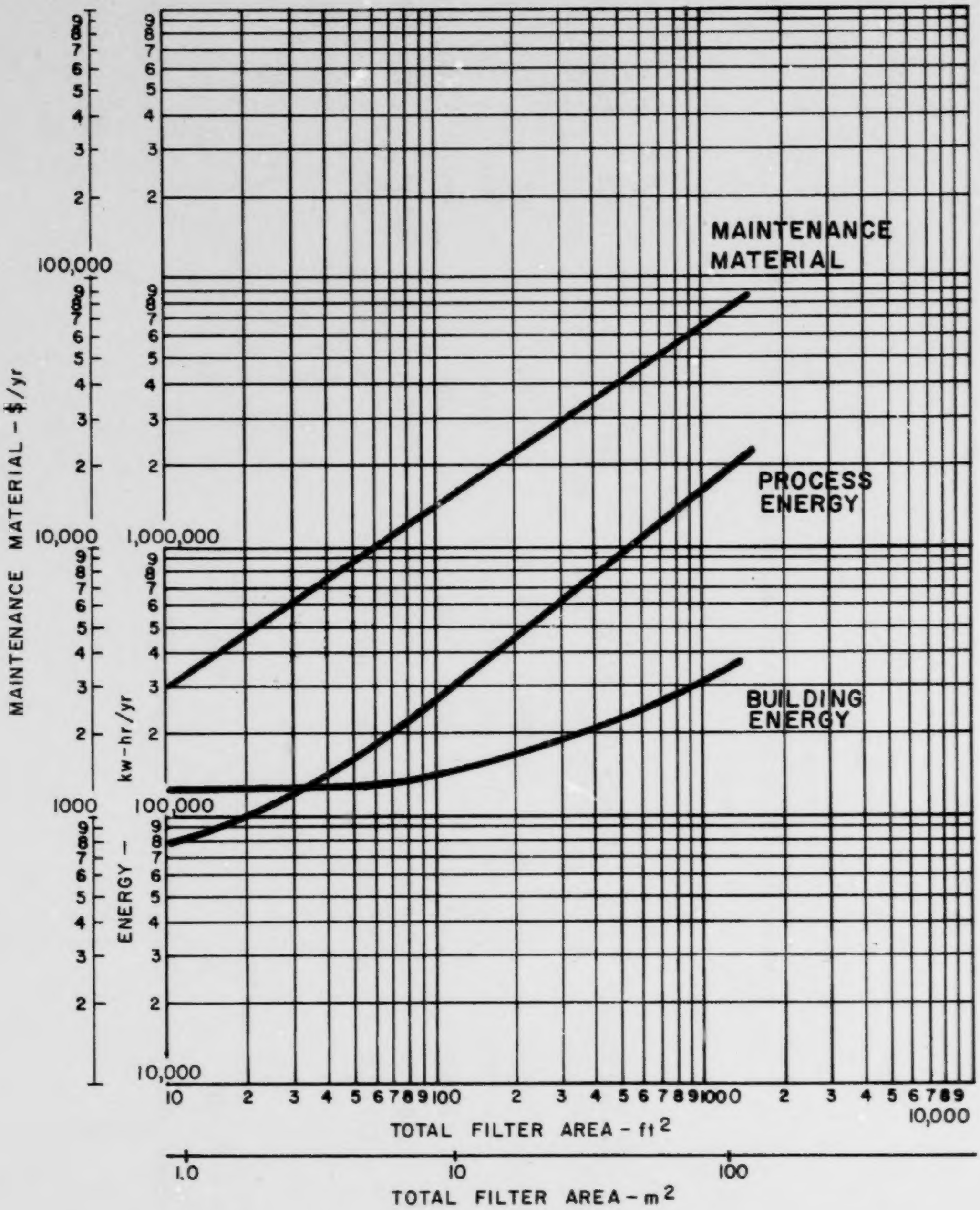


Figure 171. Operation and maintenance requirements for vacuum filters - building energy, process energy, and maintenance material.

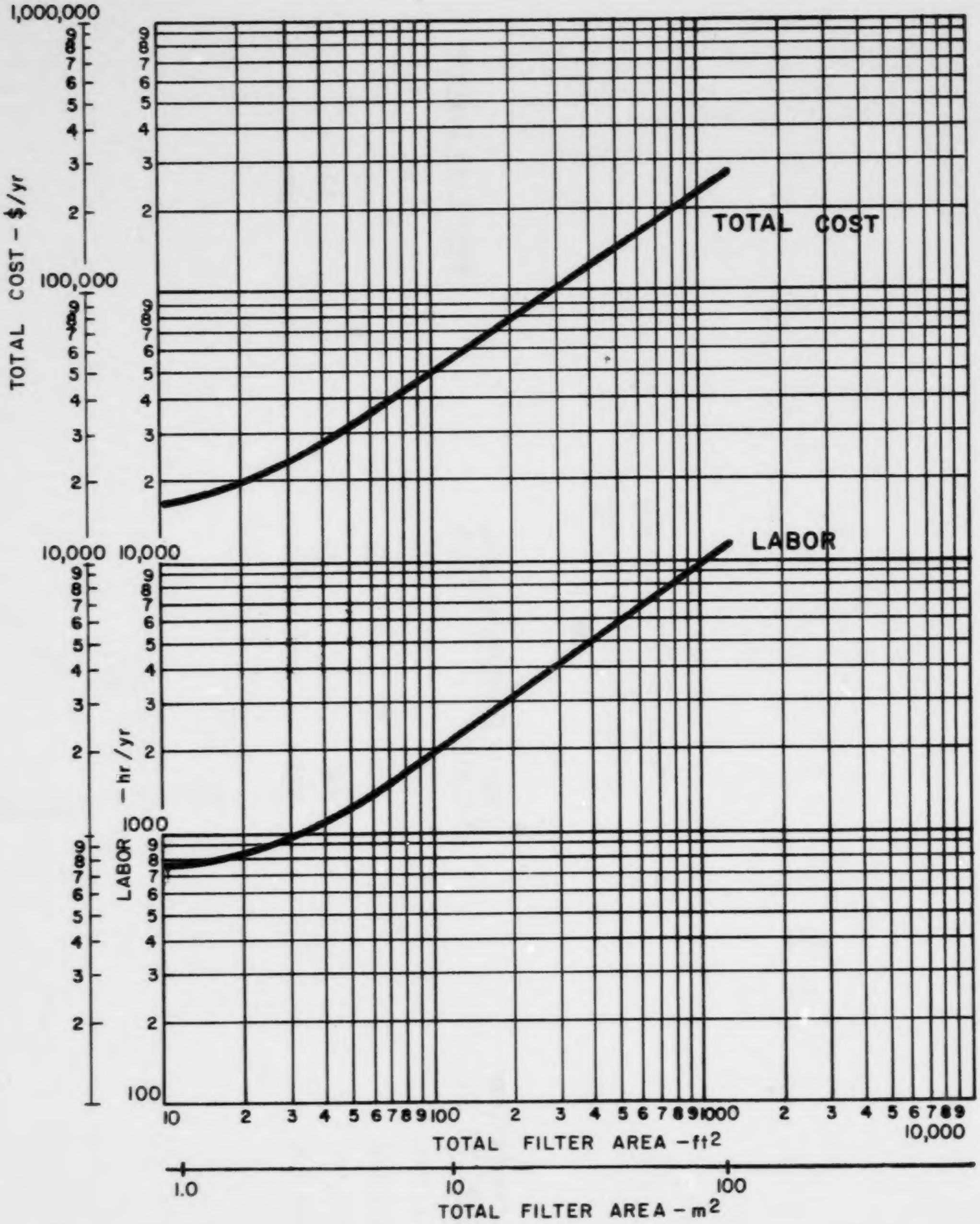


Figure 172. Operation and maintenance requirements for vacuum filters - labor and total cost.

Table 145
Conceptual Design for Sludge Dewatering Lagoons

Effective Storage Volume (ft^3)	Lagoon Dimensions (ft)		Number of Lagoons
	Length	Width	
40,000	100	20	2
400,000	330	60	2
4,000,000	440	80	10
8,000,000	440	80	20

Table 146
Construction Cost for Sludge Dewatering Lagoons

	Effective Storage Volume (ft^3)			
Cost Category	40,000	400,000	4,000,000	8,000,000
Excavation & Sitework	$2,500	$21,000	$125,000	$260,000
Concrete	700	800	10,000	19,000
Steel	100	110	1,200	2,300
Labor	2,800	20,000	69,000	110,000
Pipe & Valves	2,400	6,000	40,000	75,000
SUBTOTAL	8,500	47,910	245,200	466,300
Miscellaneous & Contingency	1,280	7,190	36,780	69,950
TOTAL COST	9,780	55,100	281,980	536,250

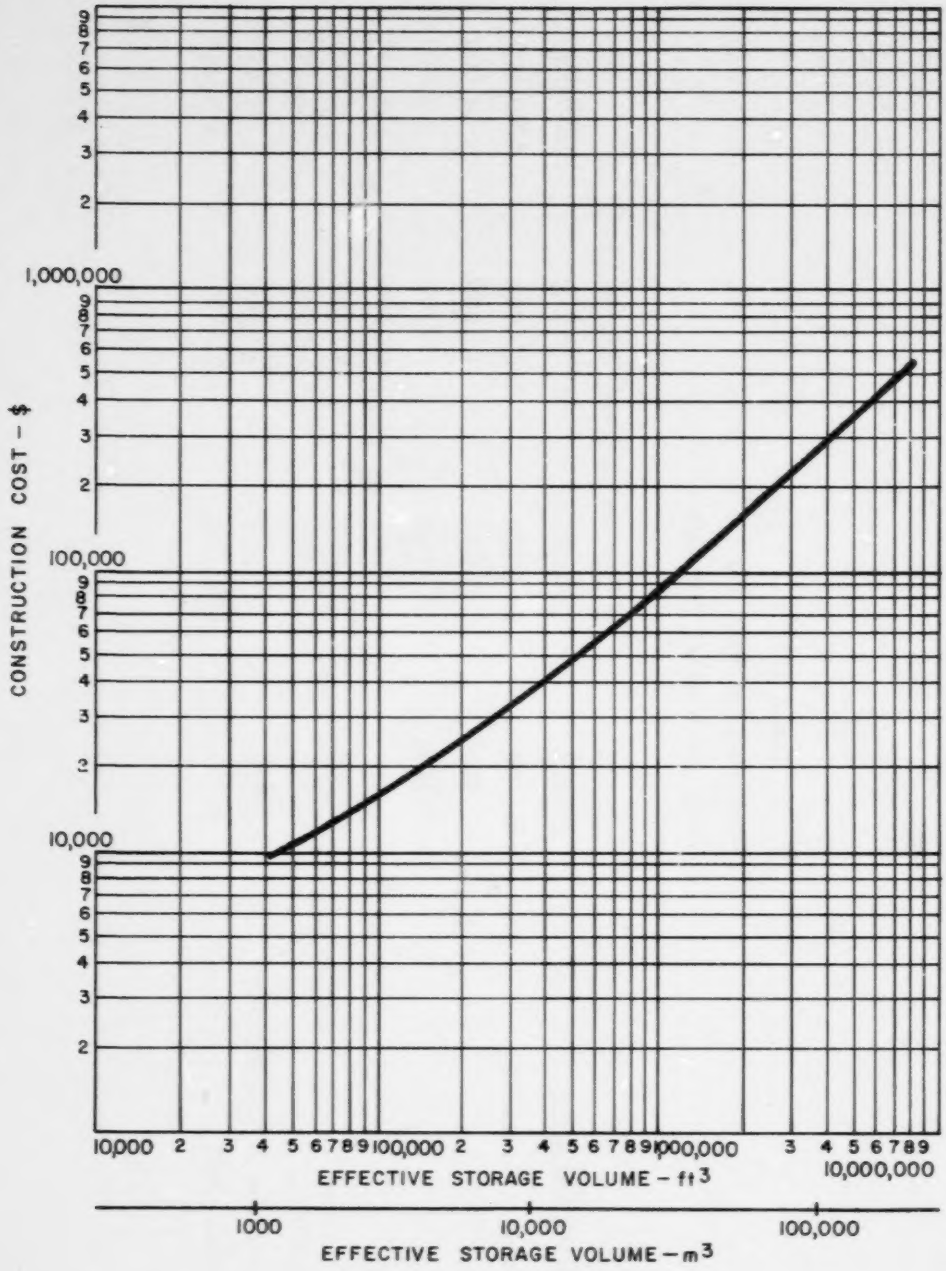


Figure 173. Construction cost for sludge dewatering lagoons.

Energy requirements are for diesel fuel used in the removal and transport of sludge. Maintenance material is for periodic lagoon grading and restoration of dikes and roadway maintenance. Labor requirements are for sludge removal and transport, and for lagoon maintenance.

Operation and maintenance requirements are summarized in Table 147 and illustrated in Figures 174 and 175.

FILTER PRESS

Construction Cost

The filter press has gained popularity for dewatering water treatment plant sludges because it can produce a high solids content cake suitable for direct disposal by landfill. The introduction of semi-automatic presses along with other labor and maintenance saving improvements has further stimulated interest in filter presses for water treatment plant sludge dewatering.

Construction costs were developed for a series of single and multiple filter press systems ranging in size from 4.3 to 896 ft^3. The largest single press utilized in the cost estimates had a capacity of 224 ft^3. Conceptual designs providing press sizing information are shown in Table 148. A typical arrangement for a filter press installation is shown in Figure 176. The construction costs include the filter press, feed pumps (including one standby), a lime storage bin and feeders, a sludge conditioning and mixing tank, an acid wash system, and housing.

Construction costs are summarized in Table 149 and are illustrated in Figure 177.

Operation and Maintenance Cost

Operation and maintenance costs were developed for a 4 percent feed sludge concentration, a filter loading of 5 to 5.6 lb of dry solids/ft^3 per hour, a dry solids density of 75 lb/ft^3, and 19 hr of operation/day. The remaining 5 hr/day are devoted to press preparation, sludge removal, cleanup, and maintenance.

Most of the process energy consumed by the filter press is related to operation of the feed pump. Energy is also consumed by the open-close mechanism and the tray mover. Pumping power requirements were calculated for a solids loading of 4 percent at a cycle time of 2.25 hr, with a 0.33-hr turnaround time between cycles. Power required for chemical preparation, mixing, and feeding is also included in process energy. Energy requirements related to building heating, lighting, and ventilation were also developed using the housing area requirements presented in Table 148.

Maintenance material costs and labor requirements were estimated based on manufacturers' experience and data from several operating installations.

Operation and maintenance costs are summarized in Table 150 and illustrated in Figures 178 and 179.

Table 147

Operation and Maintenance Summary for Sludge Dewatering Lagoons

Volume of Sludge Removed (ft^3)*	Diesel Fuel (gal/yr)+	Maintenance Material ($/yr)‡	Labor (hr/yr)	Total Cost§ ($/yr)
10,000	100	$50	94	$1,040
100,000	950	220	900	9,650
500,000	4,650	600	3,600	38,690
1,000,000	8,850	900	7,000	74,880
5,000,000	42,450	2,000	30,000	321,110

*Assumes sludge density of 70 lb/ft^3 with 17 to 20 percent solids concentration.

+No. 2 diesel fuel used for loader and dump truck.

‡Exclusive of removal equipment maintenance.

§Calculated using diesel fuel at $0.45/gal and labor at $10.00/hr.

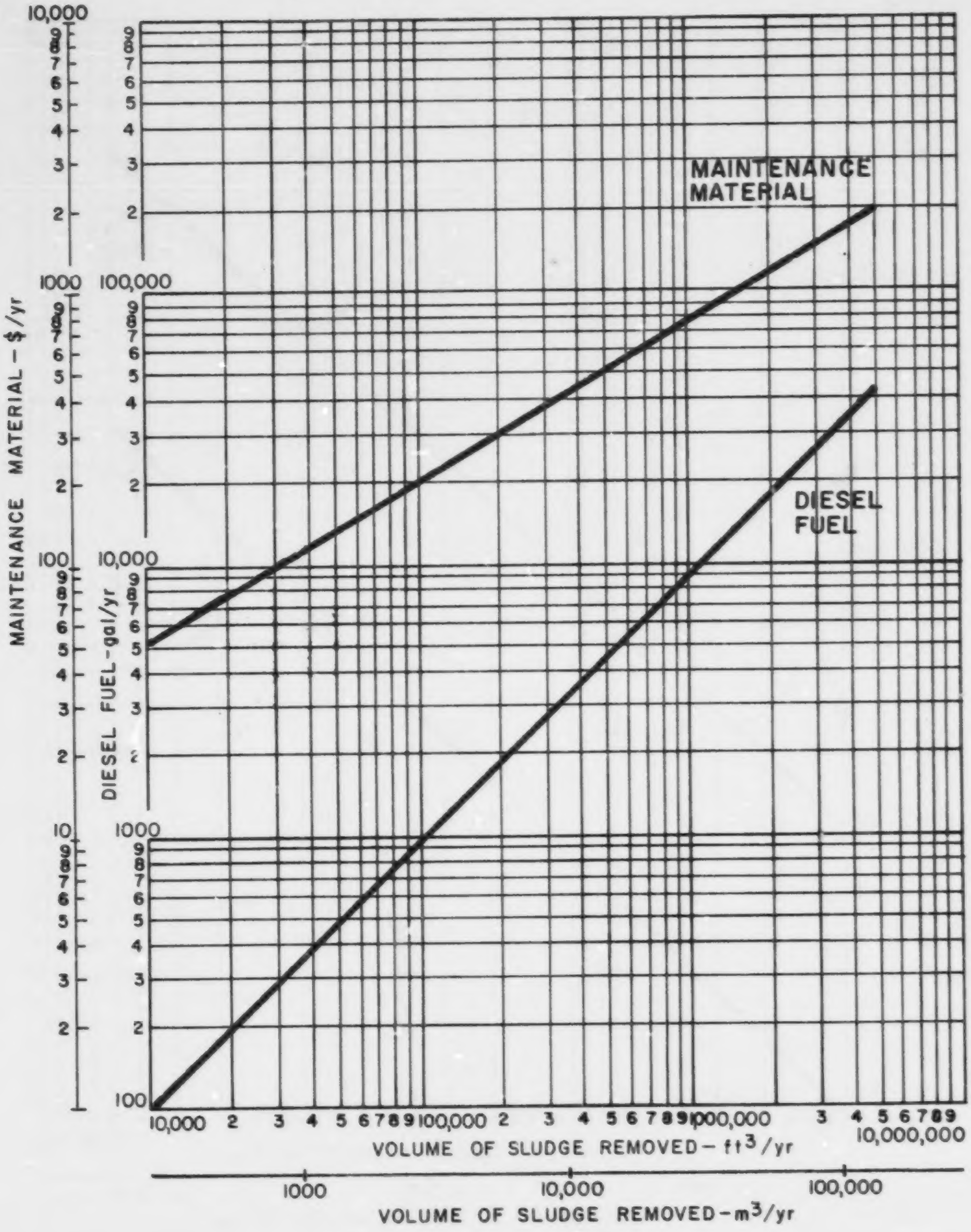


Figure 174. Operation and maintenance requirements for sludge dewatering lagoons - diesel fuel and maintenance material.

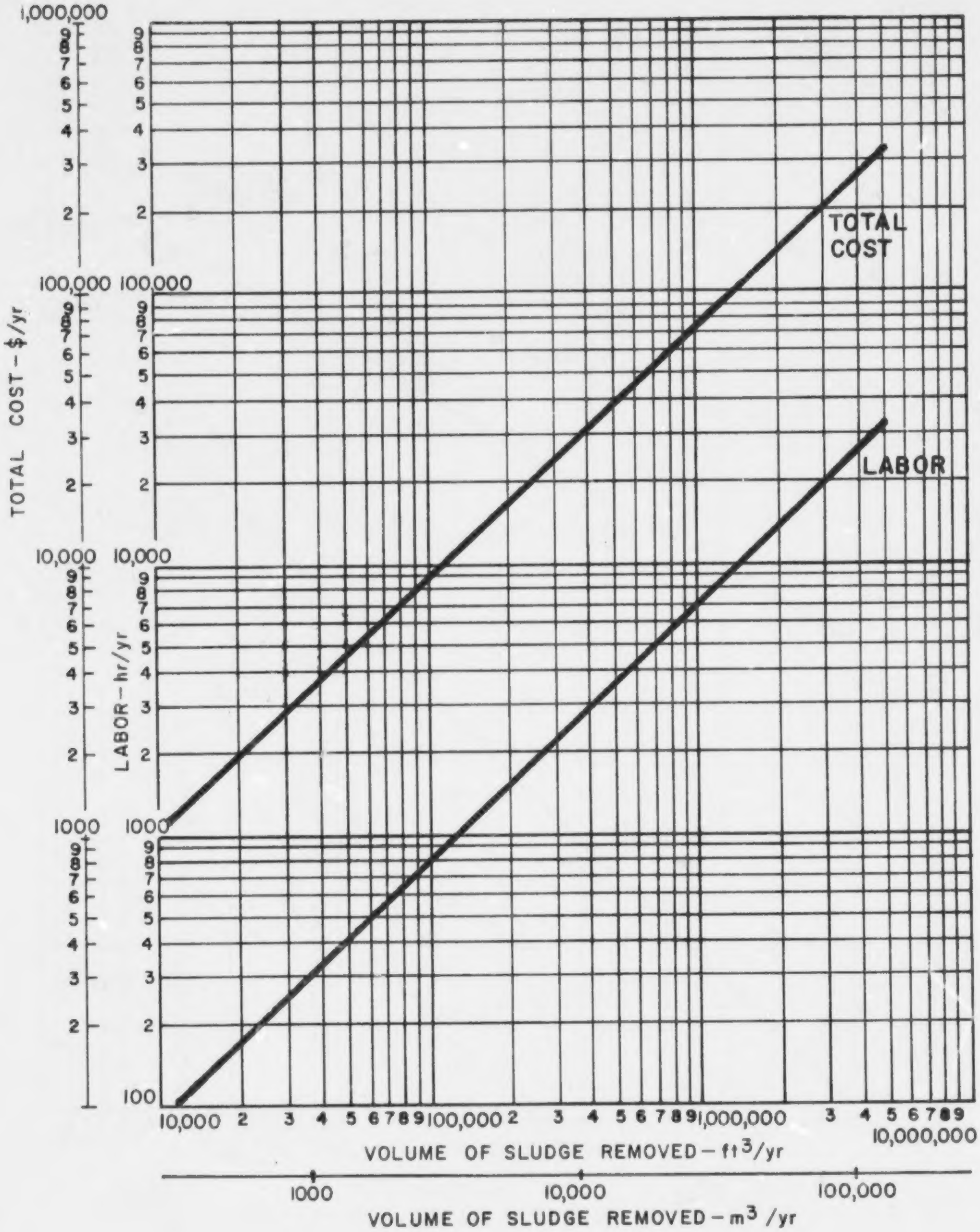
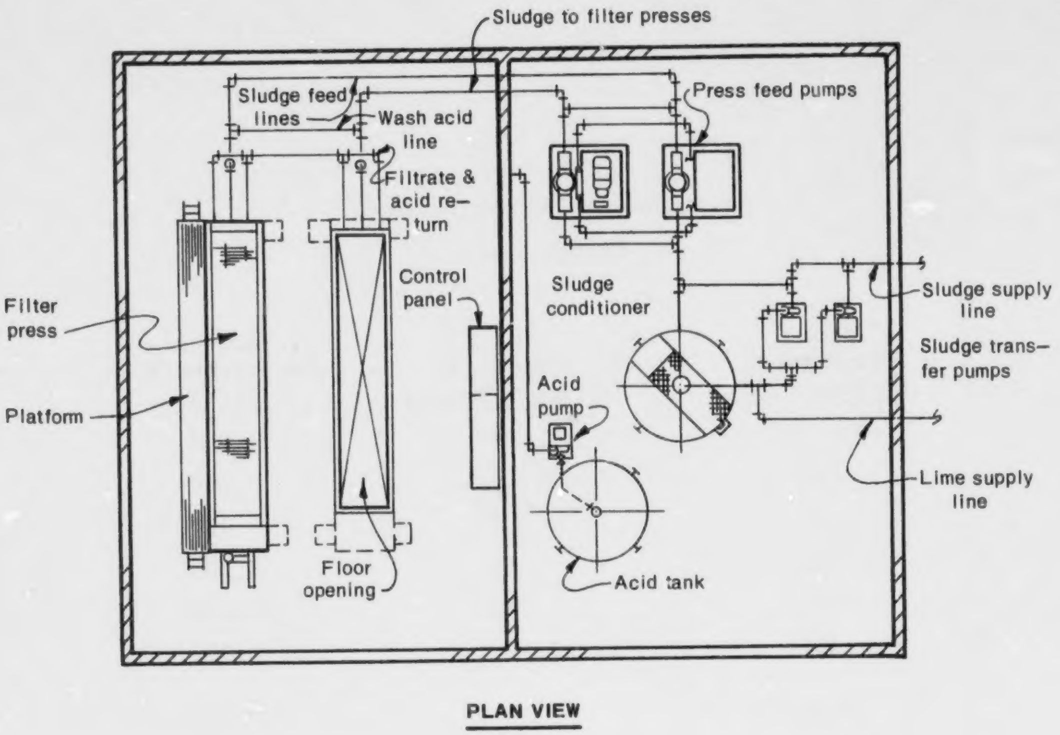


Figure 175. Operation and Maintenance requirements for sludge dewatering lagoons - labor and total cost.

Table 148
Conceptual Design for Filter Press

Total Filter Press Volume (ft^3)	Number of Filter Presses	Housing Requirements (ft^2)
4.3	1	1,200
24	1	2,200
50	1	2,400
224	1	3,300
448	2	4,550
896	4	7,000


Sludge to filter presses
Sludge feed lines
Wash acid line
Filtrate & acid return
Press feed pumps
Filter press
Platform
Control panel
Floor opening
Sludge conditioner
Sludge supply line
Sludge transfer pumps
Acid pump
Lime supply line
Acid tank
PLAN VIEW

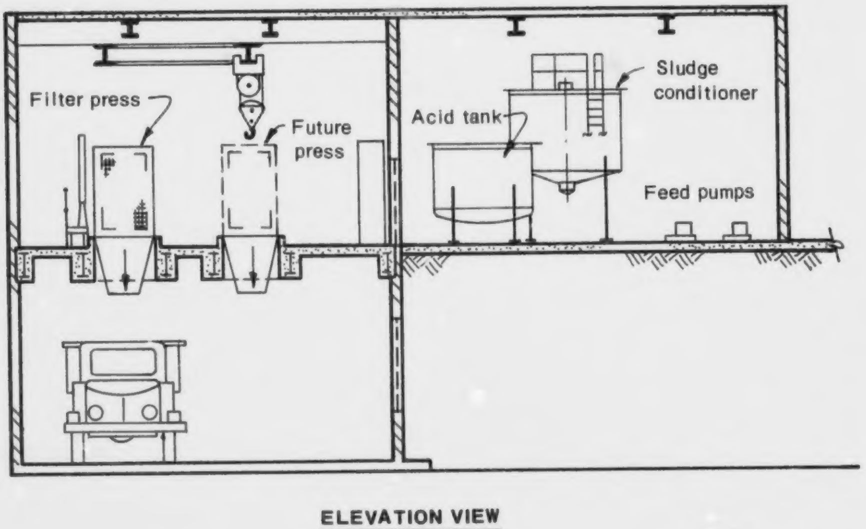

Filter press
Future press
Acid tank
Sludge conditioner
Feed pumps
ELEVATION VIEW

Figure 176. Typical filter press installation.

Table 149

Construction Cost for Filter Press

Cost Category	Total Filter Press Volume (ft^3)					
	4.3	24	50	224	448	896
Manufactured Equipment	$92,000	$168,000	$245,000	$425,000	$680,000	$1,245,000
Labor	27,600	50,400	75,000	127,000	190,000	350,000
Pipe & Valves	3,000	3,200	4,000	5,000	6,600	10,000
Electrical & Instrumentation	2,700	2,800	3,000	3,500	6,400	11,000
Housing	54,000	90,200	97,200	129,000	160,000	224,000
SUBTOTAL	179,300	314,600	424,200	689,500	1,043,000	1,840,000
Miscellaneous & Contingency	26,900	47,200	63,630	103,430	156,450	276,000
TOTAL COST	206,200	361,800	487,830	792,930	1,199,450	2,116,000

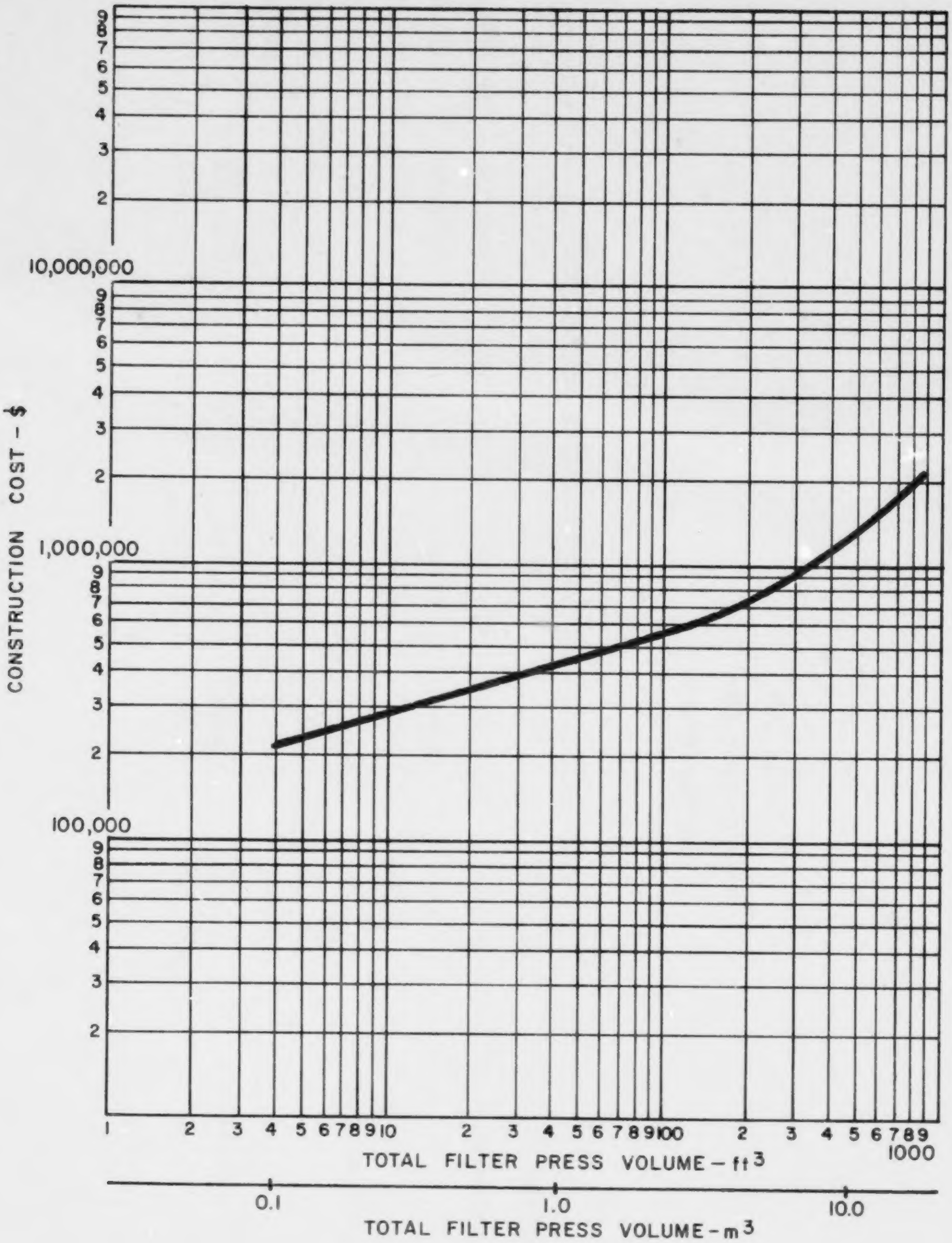


Figure 177. Construction cost for filter press.

Table 150

Operation and Maintenance Summary for Filter Press*

Filter Press Volume (ft^3)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost+ ($/yr)
	Building	Process	Total			
4.3	123,100	24,400	147,500	$1,000	6,935	$74,780
24	225,700	64,000	289,700	1,800	6,935	79,840
50	246,200	112,000	358,200	2,600	8,400	97,350
224	338,600	320,000	658,600	4,600	10,400	128,360
448	466,800	624,000	1,090,800	7,900	18,700	227,620
896	718,200	1,240,000	1,958,200	13,000	34,000	411,750

*Process energy, maintenance material, and labor requirements are typical for a 4 percent feed sludge concentration, a filter loading of 5-5.6 lb dry solids/ft^3 per hr, a dry solids density of 75 lb/ft^3, and 19 hr of operation/day.

+Calculated using $0.03/kw-hr and $10.00/hr of labor.

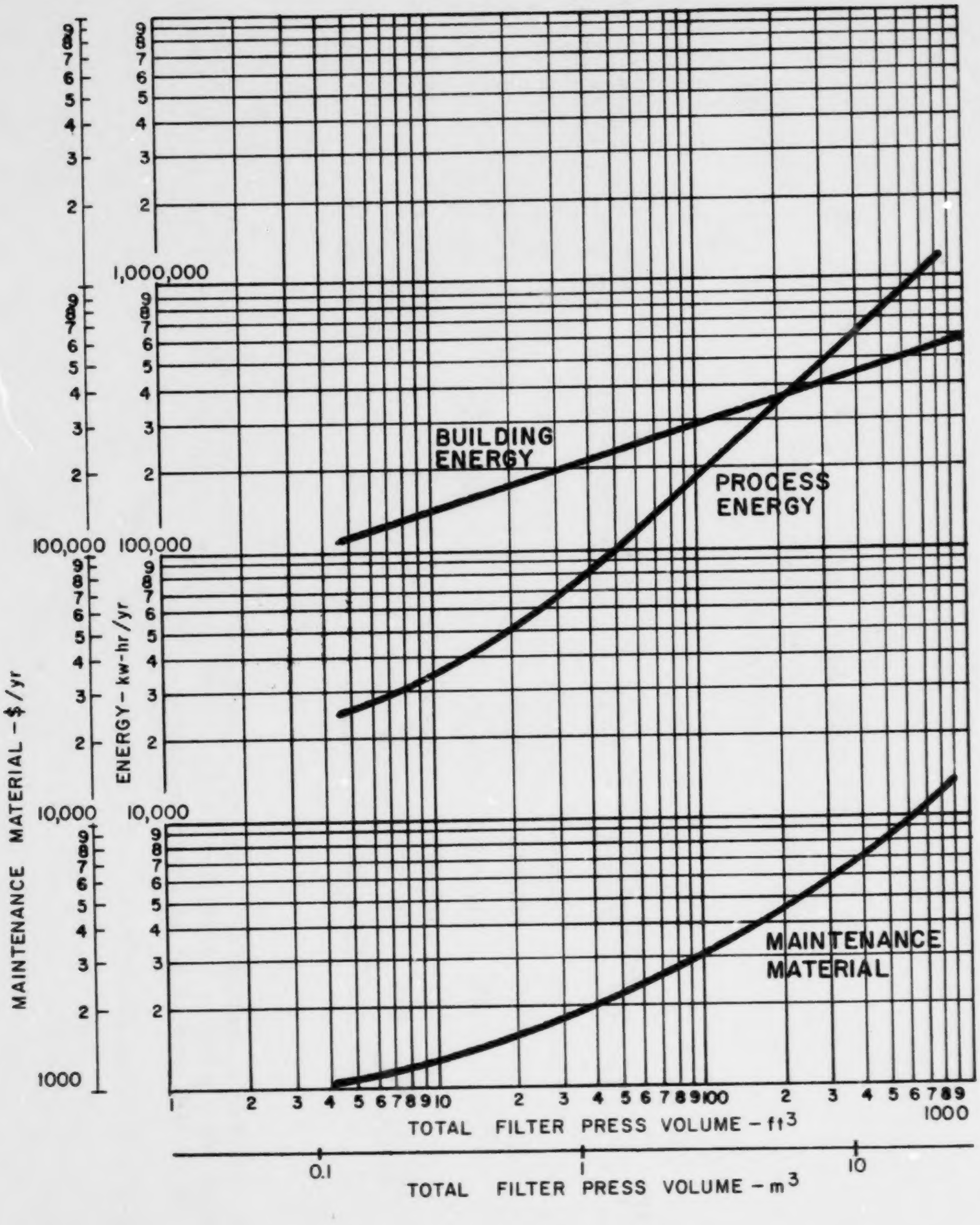


Figure 178. Operation and maintenance requirements for filter press - building energy, process energy and maintenance material.

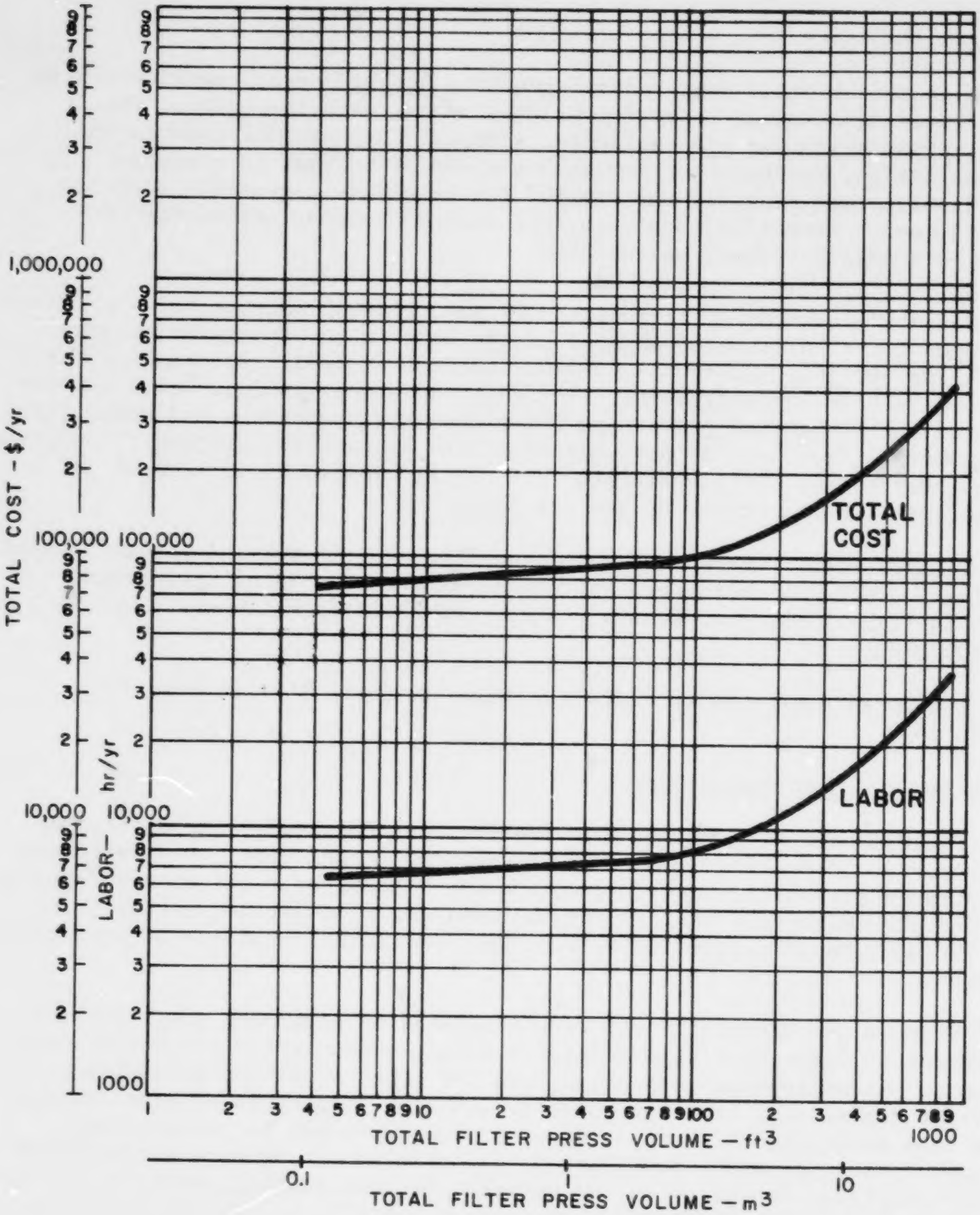


Figure 179. Operation and maintenance requirements for filter press - labor and total cost.

DECANTER CENTRIFUGES

Construction Cost

Decanter or solid bowl centrifuges have had widespread application in the dewatering of water treatment plant sludges, with the bulk of the applications being for lime softening sludges. Recent improvements in machine design, however, coupled with the use of polymer as a sludge conditioner, have expanded the application to alum sludges with reported good success. Generally, a sludge cake with 20 percent solids can be produced from a 1-percent solids feed.

Costs of decanter-style centrifuges and related appurtenances have been developed for a full-scale range of single units with capacities ranging from 10 to 500 gpm. Table 151 presents conceptual design information for machines in this capacity range. The costs developed include those for the decanter centrifuge and provisions for preparation, storage, and application of polymers. The costs do not include sludge or centrate pumping or dewatered sludge conveyance. It was assumed that centrifuges would be located for bottom discharge to trucks or storage bins.

Housing requirements were developed from equipment manufactuers' layout drawings. Building costs were estimated using the building arrangement shown in Figure 180, they assume a two-story building of concrete block construction.

Estimated construction costs are shown in Table 152 and also in Figure 181.

Operation and Maintenance Cost

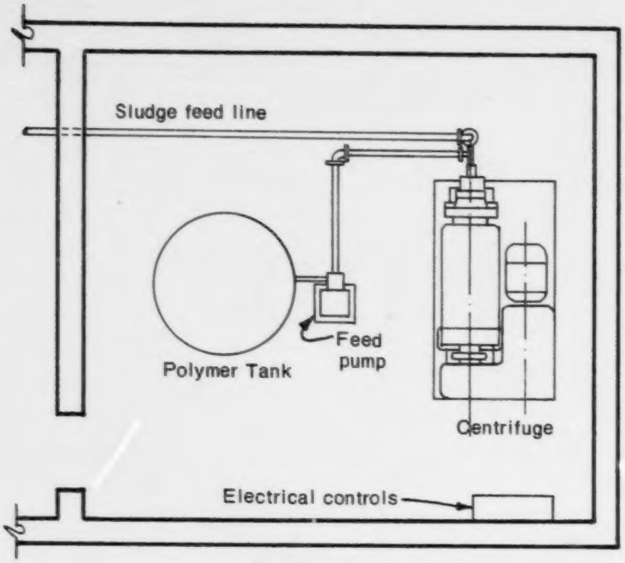
Process energy usage was computed from manufacturers' information on connected and operating horsepower for main drive and back drive units and for polymer preparation and feed equipment. The power requirements reported are for the relatively new, low-speed machines. The process energy does not include energy related to feed sludge pumping and handling of dewatered sludge.

Maintenance material costs were furnished by equipment suppliers and represent an industry-wide average for annual expenditures for replacement parts and miscellaneous components, and for general machine maintenance. Conveyor replacement or resurfacing of conveyor flights is a major maintenance task associated with decanter centrifuges and may be required as frequently as once every 8,000 hr, or as infrequently as once every 30,000 hr of operation, depending on the material of construction, service conditions, and other factors.

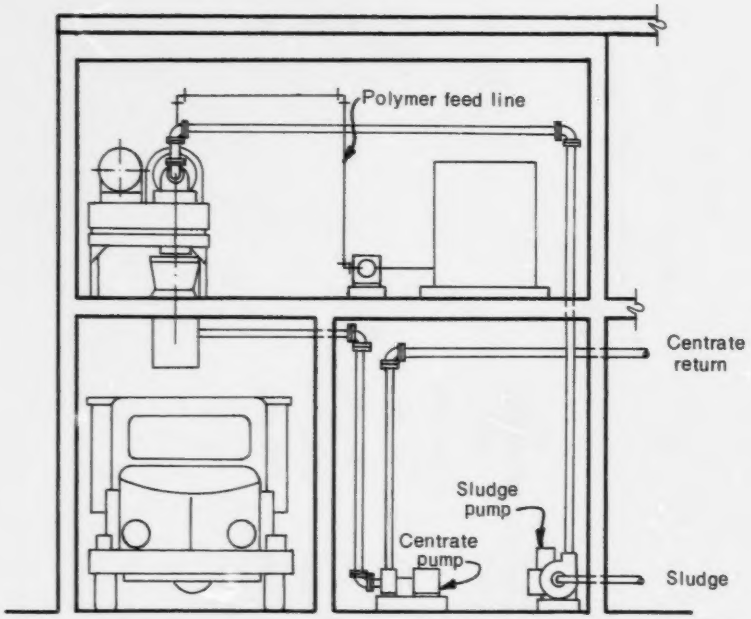
Labor requirements for operation and maintenance were computed based on 24 hr of continuous operation. The major portion of the operating labor is devoted to machine start-up and adjustment, polymer preparation, and occasional maintenance involving machine and motor lubrication.

Table 151
Conceptual Design for
Decanter Centrifuges

Machine Capacity		Number of Machines	Housing area (ft^2)
gpm	gpd		
10	14,400	1	1,000
25	36,000	1	1,200
38	54,720	1	1,200
250	360,000	1	2,100
500	720,000	1	2,300


Sludge feed line
Feed pump
Polymer Tank
Centrifuge
Electrical controls

PLAN VIEW


Polymer feed line
Centrate return
Sludge pump
Centrate pump
Sludge

SECTION VIEW

Figure 180. Typical decanter centrifuge installation.

Table 152

Construction Cost for Decanter Centrifuges

Cost Category	Machine Capacity (gpm)				
	10	25	38	250	500
Manufactured Equipment	$ 65,500	$75,000	$90,000	$205,000	$295,000
Labor	23,000	26,400	31,000	53,000	88,000
Pipe and Valves	7,000	7,500	8,300	24,000	38,000
Electrical & Instrumentation	4,500	4,500	5,000	10,800	10,800
Housing	44,000	53,000	53,000	88,000	94,000
SUBTOTAL	144,000	166,400	187,300	380,800	525,800
Miscellaneous & Contingency	21,600	24,960	28,100	57,120	78,870
TOTAL COST	165,600	191,360	215,400	437,920	604,670

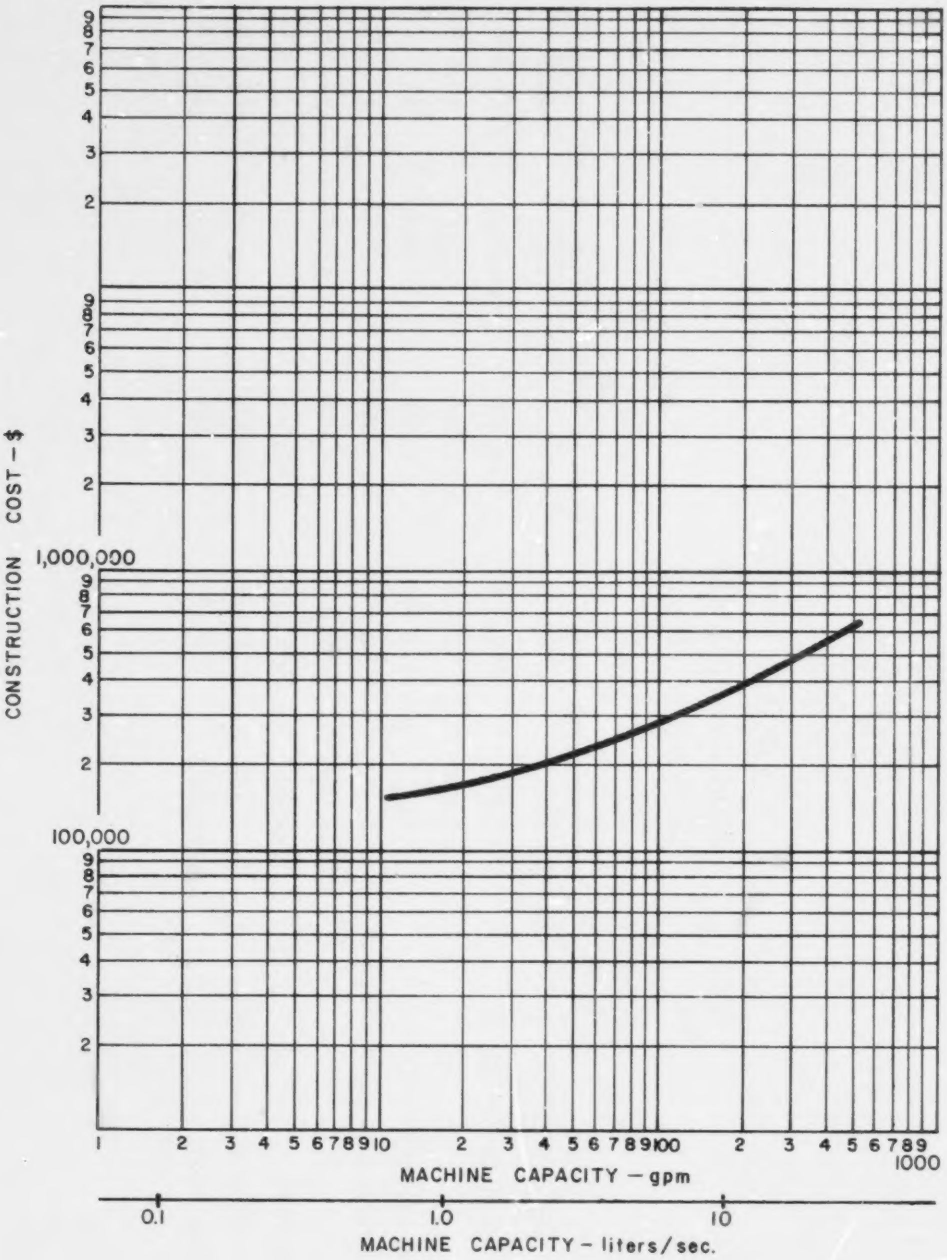


Figure 181. Construction cost for decanter centrifuges.

A summary of operation and maintenance requirements is presented in Table 153 and illustrated in Figures 182 and 183. It should be noted that total operation and maintenance costs will vary considerably, depending on hours per day of operation. If operation is less than 24 hr/day, appropriate corrections should be made in operation and maintenance requirements.

BASKET CENTRIFUGES

Construction Cost

Basket style centrifuges, because of design and operating features, are ideally suited to dewatering of light, delicate, hard-to-handle sludge encountered in water treatment. With the introduction of automatic machines that operate on a preprogrammed cycle with minimal operator attention, the application of basket centrifuges has greatly expanded for water treatment plant sludge dewatering.

Construction costs were developed for single and multiple units capable of handling alum sludge. For equipment selection purposes, it was assumed that the settled sludge is concentrated to a 1-percent solids sludge stream before centrifugation. Centrifuges were selected to produce a sludge cake with a minimum solids content of 20 percent. Conceptual designs used in the cost estimates are presented in Table 154.

In addition to the basic machines, the costs include equipment for polymer preparation, storage, and application. The costs do not include those for sludge and centrate pumping, sludge conveying, and sludge storage. It was assumed that centrifuges are located for bottom discharge to trucks or storage bins.

Housing requirements were developed from equipment manufacturers' recommended layouts. Building costs were estimated for a two-story structure of concrete and concrete block construction of a general arrangement, as shown in Figure 184.

Table 155 and Figure 185 present construction costs of basket centrifuge installations as a function of total installed machine capacity.

Operation and Maintenance Cost

Electrical energy requirements were computed from connected and operating horsepower information provided by equipment manufacturers. Basket centrifuge operating horsepower, computed on the basis of a complete cycle involving machine acceleration, sludge feeding, skimming, decelerating, and sludge plowing, averages 40 to 60 percent of the connected horsepower. Electrical power for polymer preparation and feeding is included, but energy for sludge pumps and sludge conveying equipment is not included.

Maintenance material costs were furnished by equipment manufacturers and represent an industrywide average of annual expenditures for maintenance, replacement parts, lubrication, and other consumable items associated with basket centrifuge operation.

Table 153

Operation and Maintenance Summary for Decanter Centrifuges

Feed Sludge Flow		Energy (kw-hr/yr)			Maintenance	Labor	Total Cost*
gpm	gpd	Building	Process	Total	Material ($/yr)	(hr/yr)	($/yr)
10	14,400	102,600	11,980	114,580	$1,500	730	$12,240
25	36,000	123,120	32,680	155,800	3,000	1,095	18,620
38	54,720	123,120	42,820	165,940	3,500	1,825	26,730
250	360,000	215,460	326,750	542,210	10,000	2,190	48,170
500	720,000	235,980	653,500	889,480	15,000	3,285	74,530

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

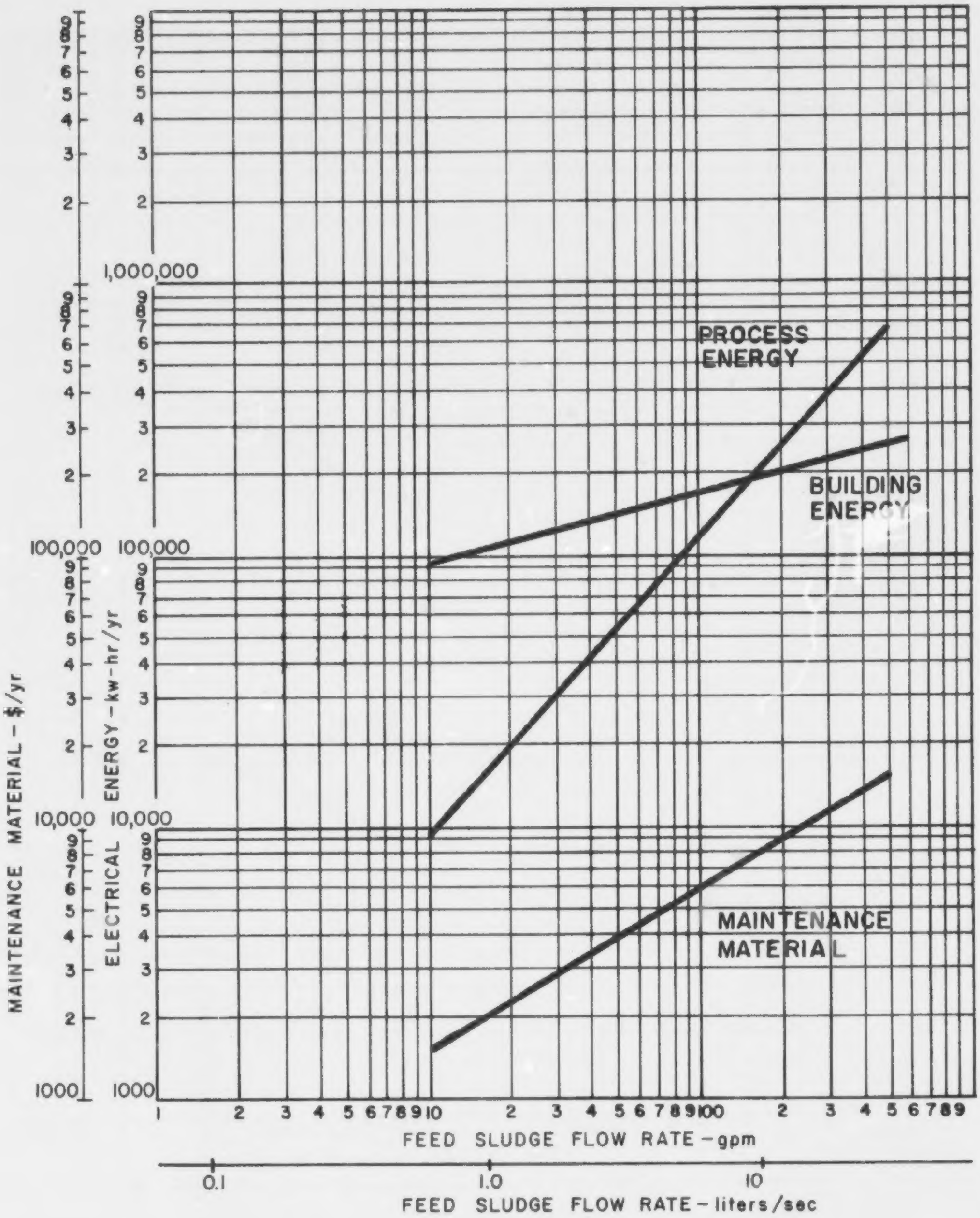


Figure 182. Operation and maintenance requirements for decanter centrifuges - building energy, process energy and maintenance material.

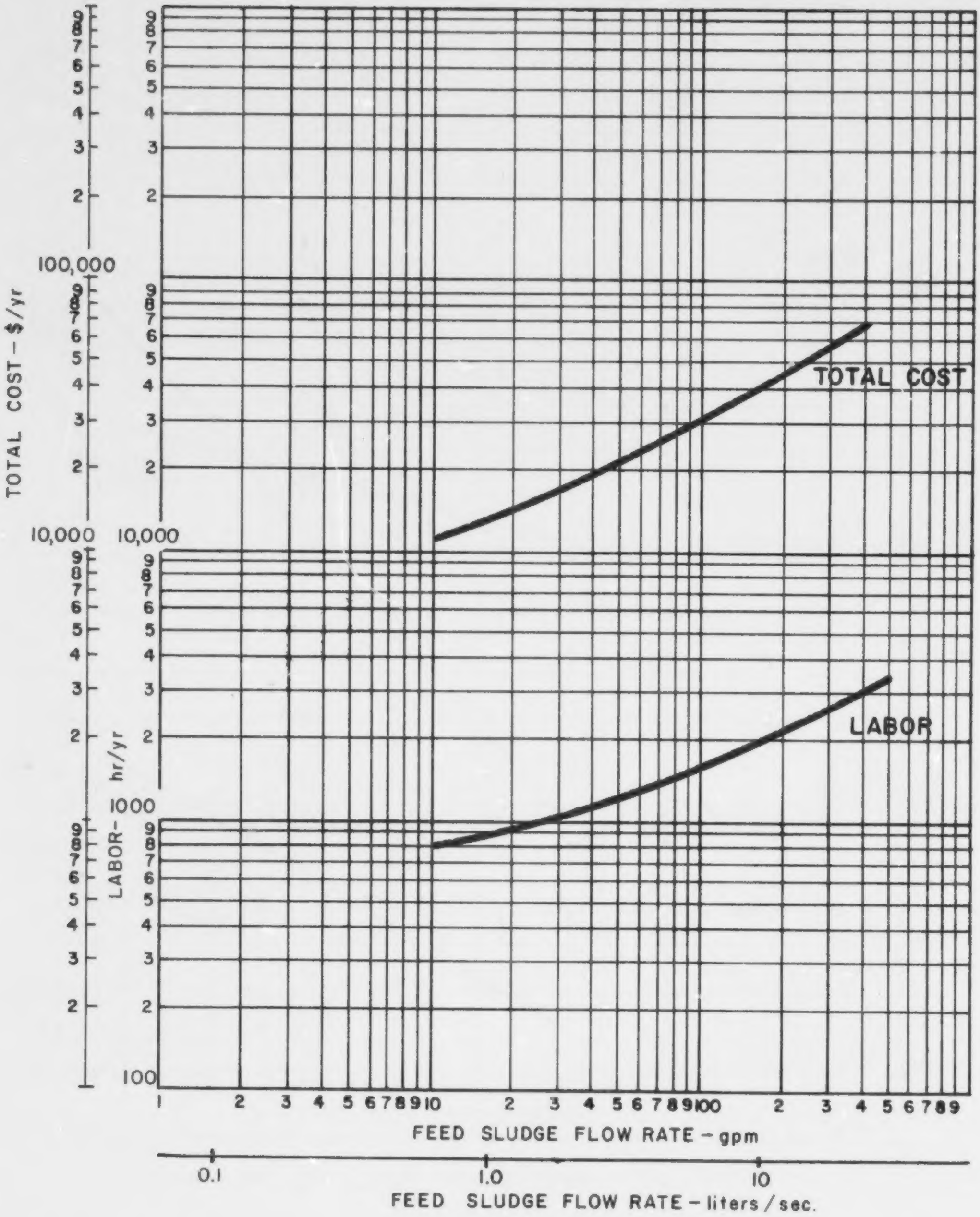


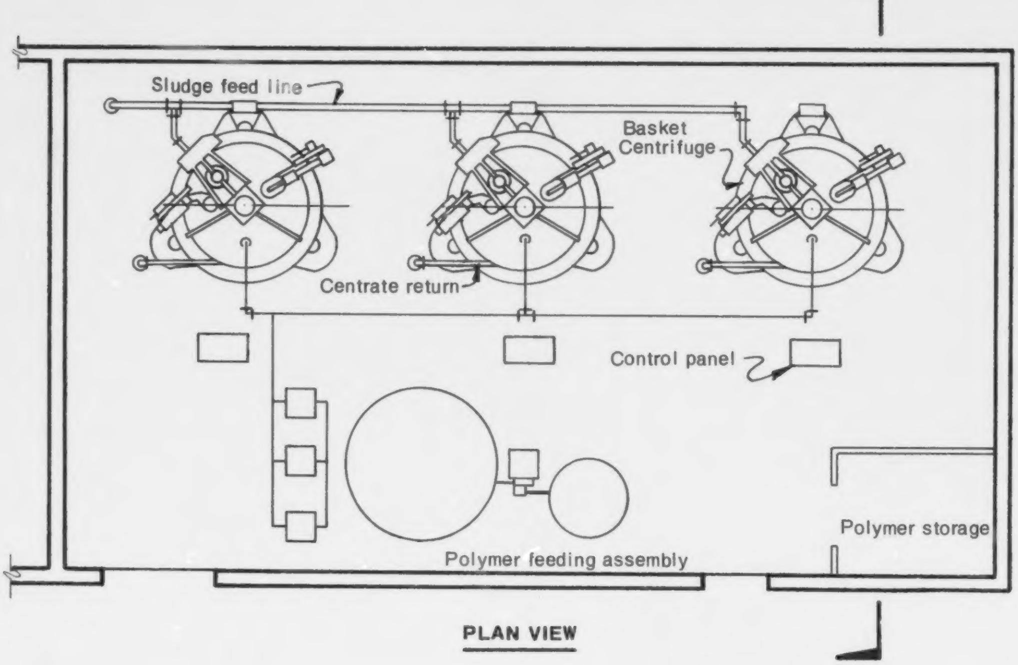
Figure 183. Operation and maintenance requirements for decanter centrifuges - labor and total cost.

Table 154

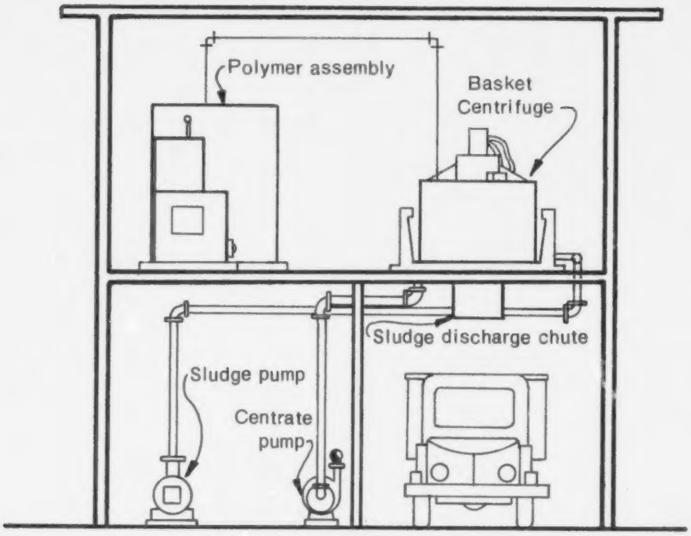
Conceptual Design for

Basket Centrifuges

Total Machine Capacity (gpd)	Machine Size (in.)	Number of Machines	Housing Requirements (ft^2)
3,600	30 x 18	1	1,600
36,000	40 x 24	1	1,600
180,000	48 x 30	3	2,400
360,000	48 x 30	6	4,800
720,000	48 x 30	12	9,600


Sludge feed line
Basket Centrifuge
Centrate return
Control panel
Polymer storage
Polymer feeding assembly

PLAN VIEW


Polymer assembly
Basket Centrifuge
Sludge discharge chute
Sludge pump
Centrate pump

SECTION VIEW

Figure 184. Typical basket centrifuge installation.

Table 155

Construction Cost for Basket Centrifuges

Cost Category	Total Machine Capacity (gpd)				
	3,600	36,000	180,000	360,000	720,000
Manufactured Equipment	$55,000	$65,000	$236,000	$440,000	$878,000
Labor	18,000	20,000	75,000	140,000	270,000
Pipe and Valves	7,200	7,200	20,800	39,700	50,000
Electrical & Instrumentation	2,500	2,500	5,300	9,500	16,000
Housing	78,000	78,000	104,000	175,000	284,000
SUBTOTAL	160,700	172,700	441,100	804,200	1,498,000
Miscellaneous & Contingency	24,100	25,900	66,170	120,630	224,700
TOTAL COST	184,800	198,600	507,270	924,830	1,722,700

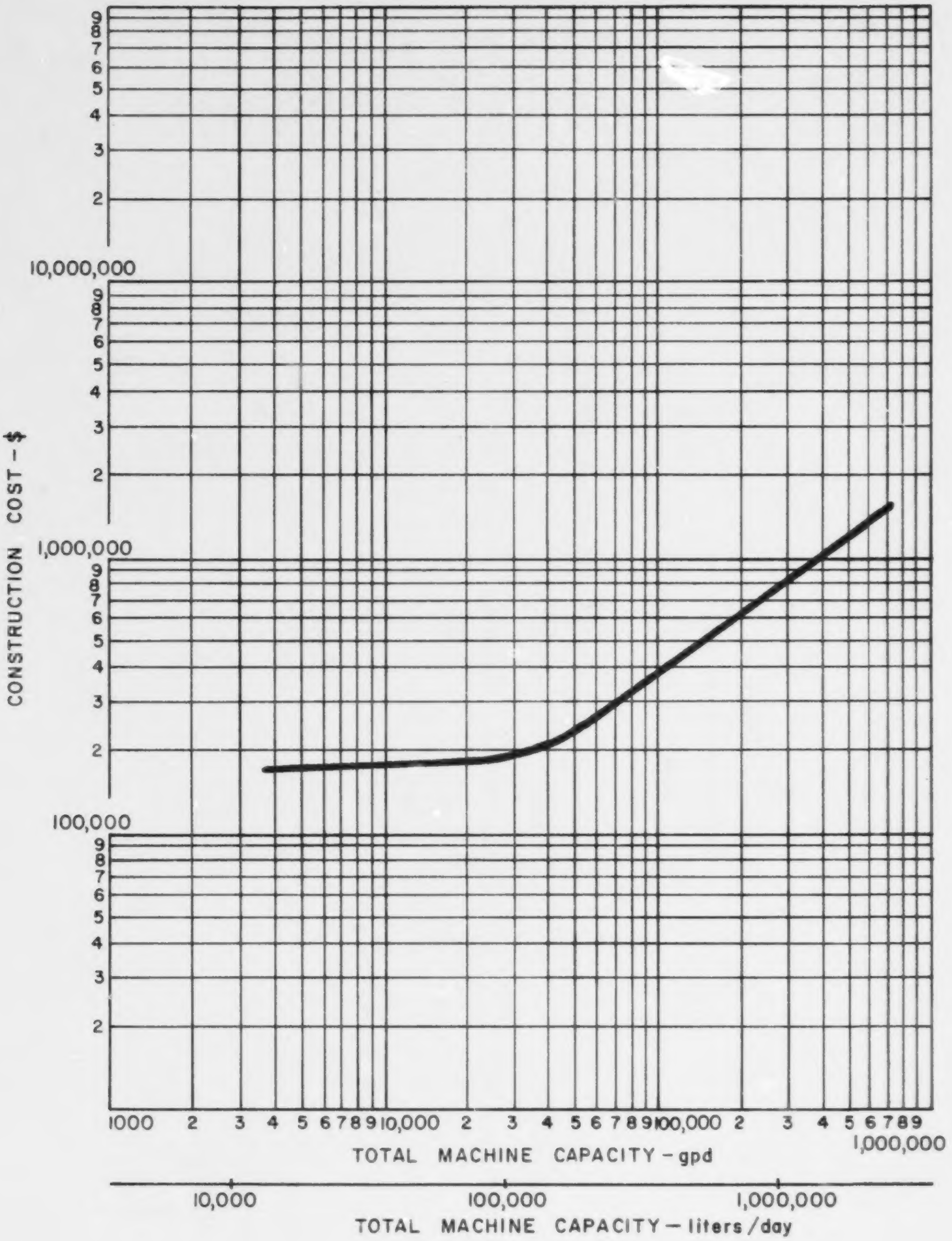


Figure 185. Construction cost for basket centrifuges.

Labor requirements for operation and maintenance assume 24 hr of continuous operation. The major portion of the operating labor is devoted to machine start-up and adjustment, polymer preparation, and required maintenance.

Operation and maintenance requirements are presented in Table 156 and Figures 186 and 187. Operation and maintenance costs will vary widely depending on sludge dewatering characteristics and specific operating conditions related to the installation; appropriate adjustment should be made if conditions vary significantly from those stated above.

SAND DRYING BEDS

Construction Cost

Sand drying beds are an economical method of producing a dry sludge cake with little or no pretreatment required, although polymer addition may be used. Dewatering is by a combination of draining and air drying, and beds perform best when both of these processes are optimized. Removal of dried sludge is normally accomplished by front-end loader. Although sand drying beds offer a low-cost approach to sludge drying, this advantage may be offset by the land area required and poor performance during cold or wet periods.

Cost estimates were made for uncovered and unlined sand drying beds. The estimates include the sludge distribution piping, 9 in. of sand media overlying 9 in. of gravel media, 2-ft-high concrete dividers between beds, and an underdrain system to remove percolating water. Land costs were not included in the cost estimates. Conceptual designs that were used in estimating costs are shown in Table 157.

Presented in Figure 188 are the estimated construction costs, which are also shown in Table 158.

Operation and Maintenance Cost

Energy requirements are for a front-end loader to remove dried sludge from the beds and to prepare the bed for the next sludge application. A cleaning and preparation time of 3 hr for a 4,000 ft^2 bed, a diesel fuel consumption of 4 gal/hr, and 20 cleanings/bed per year were used to calculate fuel requirements.

Maintenance material requirements are for replacement of sand lost during bed cleaning. One-quarter inch of sand loss per cleaning was used to calculate maintenance material costs.

Labor costs are for sludge removal and bed preparation, and they are based on experience at operating installations.

Figures 189 and 190 present the operation and maintenance requirements and Table 159 summarizes these requirements.

Table 156

Operation and Maintenance Summary for Basket Centrifuges

Sludge Flow Rate (gpd)	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
	Building	Process	Total			
3,600	82,850	65,350	148,200	$1,800	510	$11,350
36,000	115,520	98,020	213,540	2,200	610	14,710
180,000	630,150	588,150	1,218,300	6,600	1,700	60,150
360,000	1,260,290	1,176,290	2,436,580	13,200	3,000	116,300
720,000	2,457,590	2,352,590	4,810,180	26,400	5,500	225,700

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

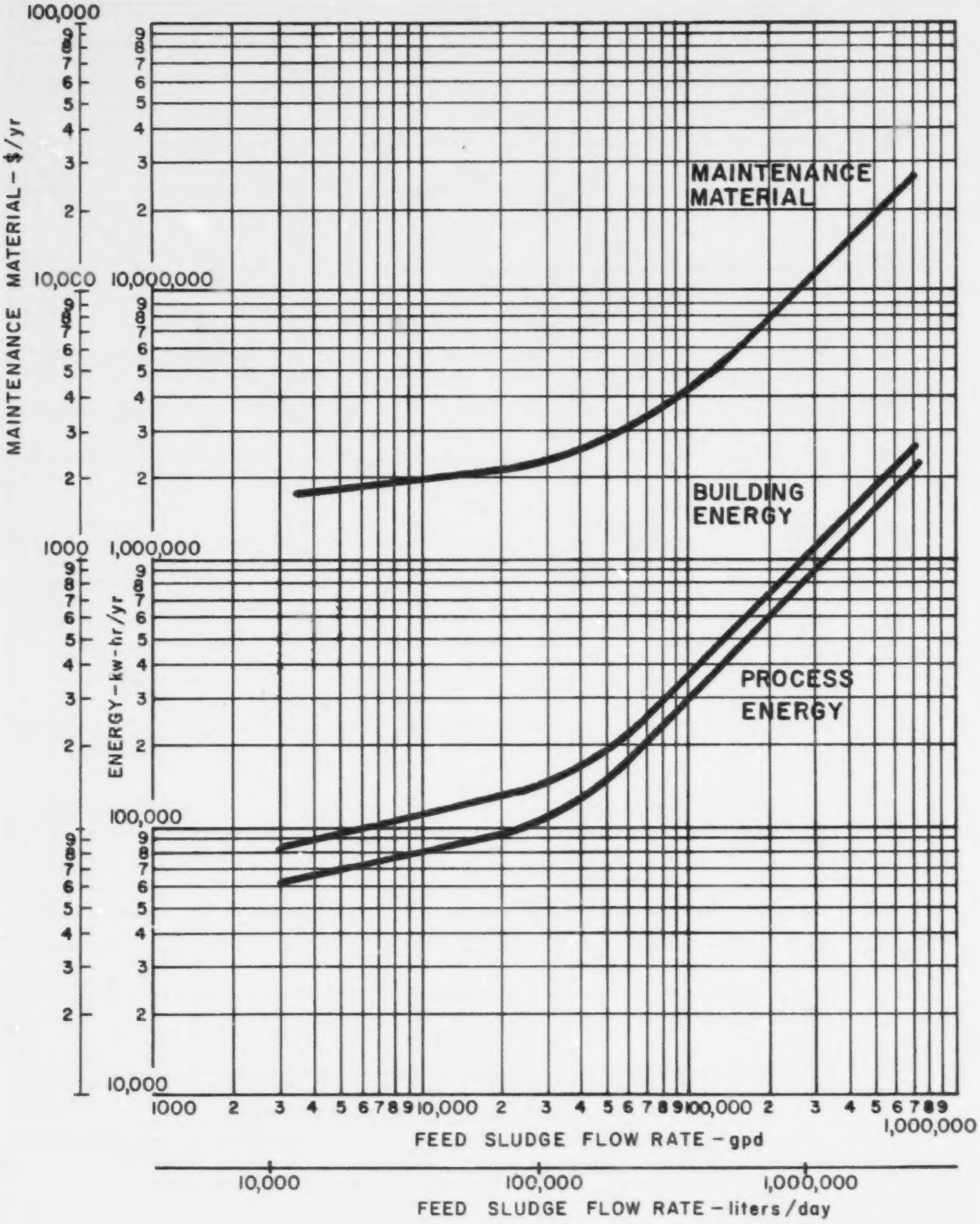


Figure 186. Operation and maintenance requirements for basket centrifuges - building energy, process energy and maintenance material.

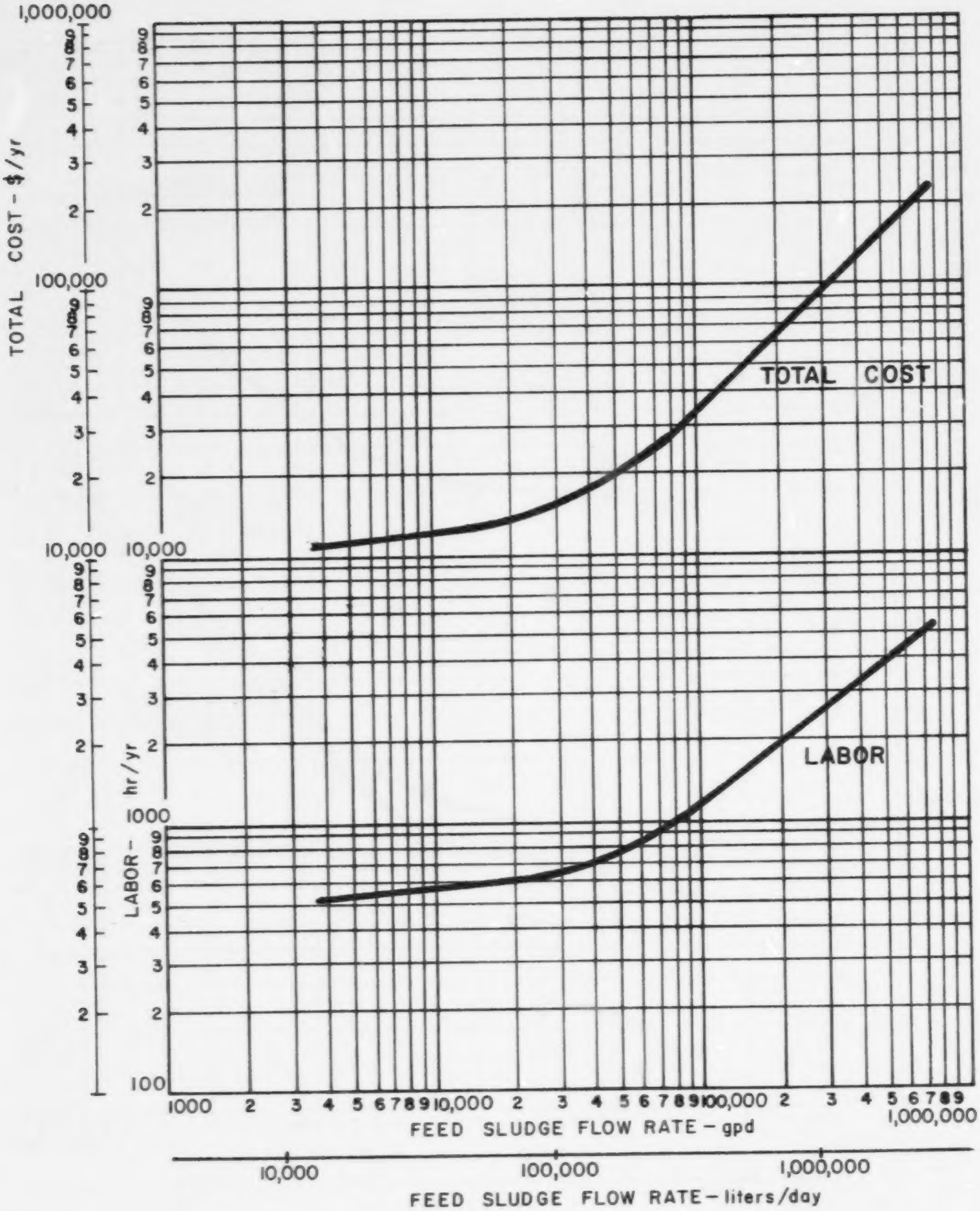


Figure 187. Operation and maintenance requirements for basket centrifuges - labor and total cost.

Table 157
Conceptual Design for
Sand Drying Beds

Total Bed Area (ft^2)	Number of Cells	Dimensions of Cell (ft)	
		Length	Width
5,000	2	100	25
10,000	4	100	25
50,000	10	100	50
100,000	10	200	50
400,000	20	200	100

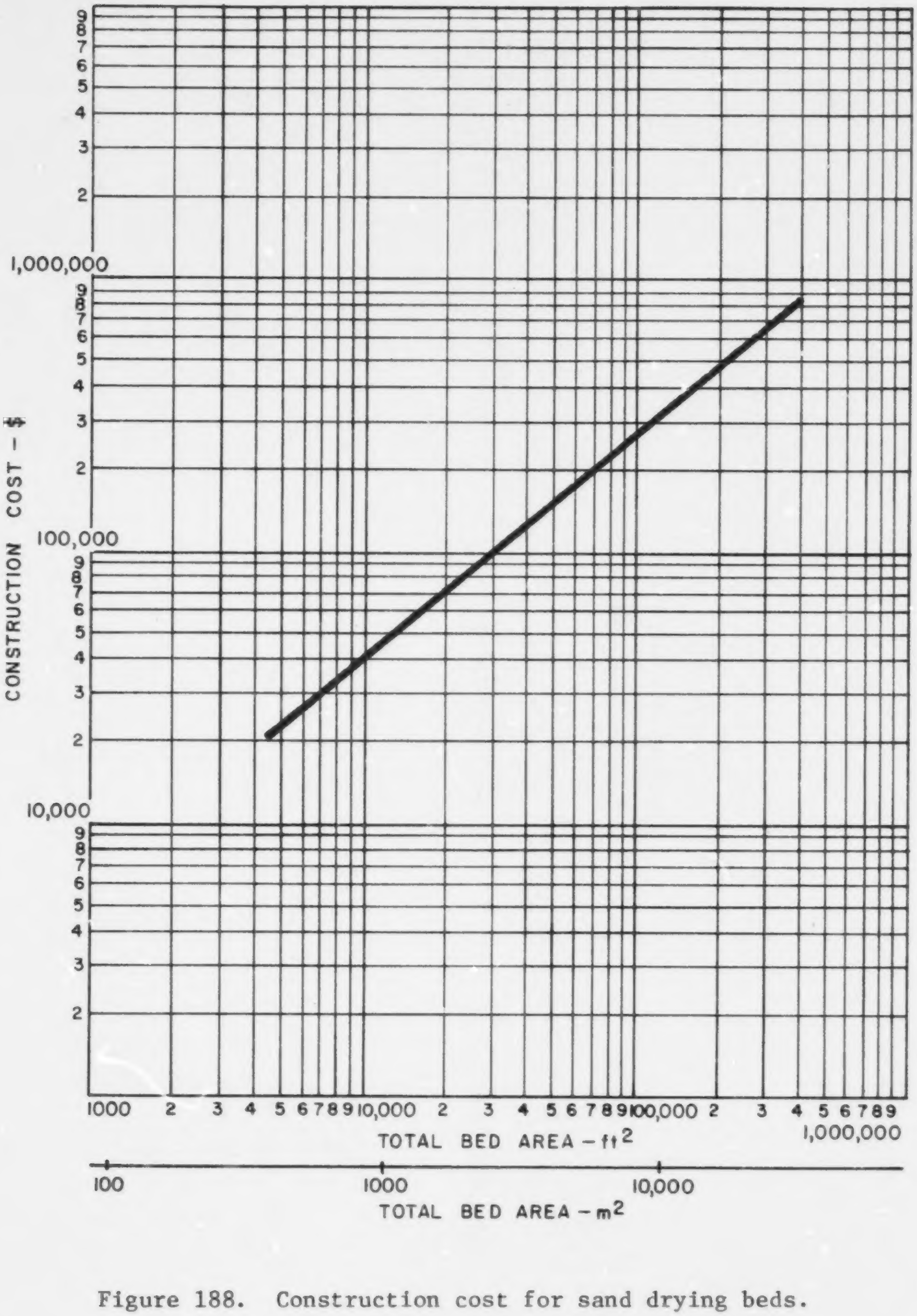


Figure 188. Construction cost for sand drying beds.

Table 158

Construction Cost for

Sand Drying Beds

	Total Bed Area (ft²)				
Cost Category	5,000	10,000	50,000	100,000	400,000
Excavation & Sitework	$ 1,000	$1,600	$7,500	$15,000	$30,000
Concrete & Media	1,800	2,400	11,400	20,800	80,000
Steel	450	700	3,000	6,000	23,000
Labor	12,000	21,000	88,000	168,000	384,000
Pipe and Valves	4,200	6,000	28,000	54,000	210,000
SUBTOTAL	19,450	31,700	137,900	263,800	727,000
Miscellaneous & Contingency	2,920	4,760	20,680	39,570	109,050
TOTAL COST	22,370	36,460	158,580	303,370	836,050

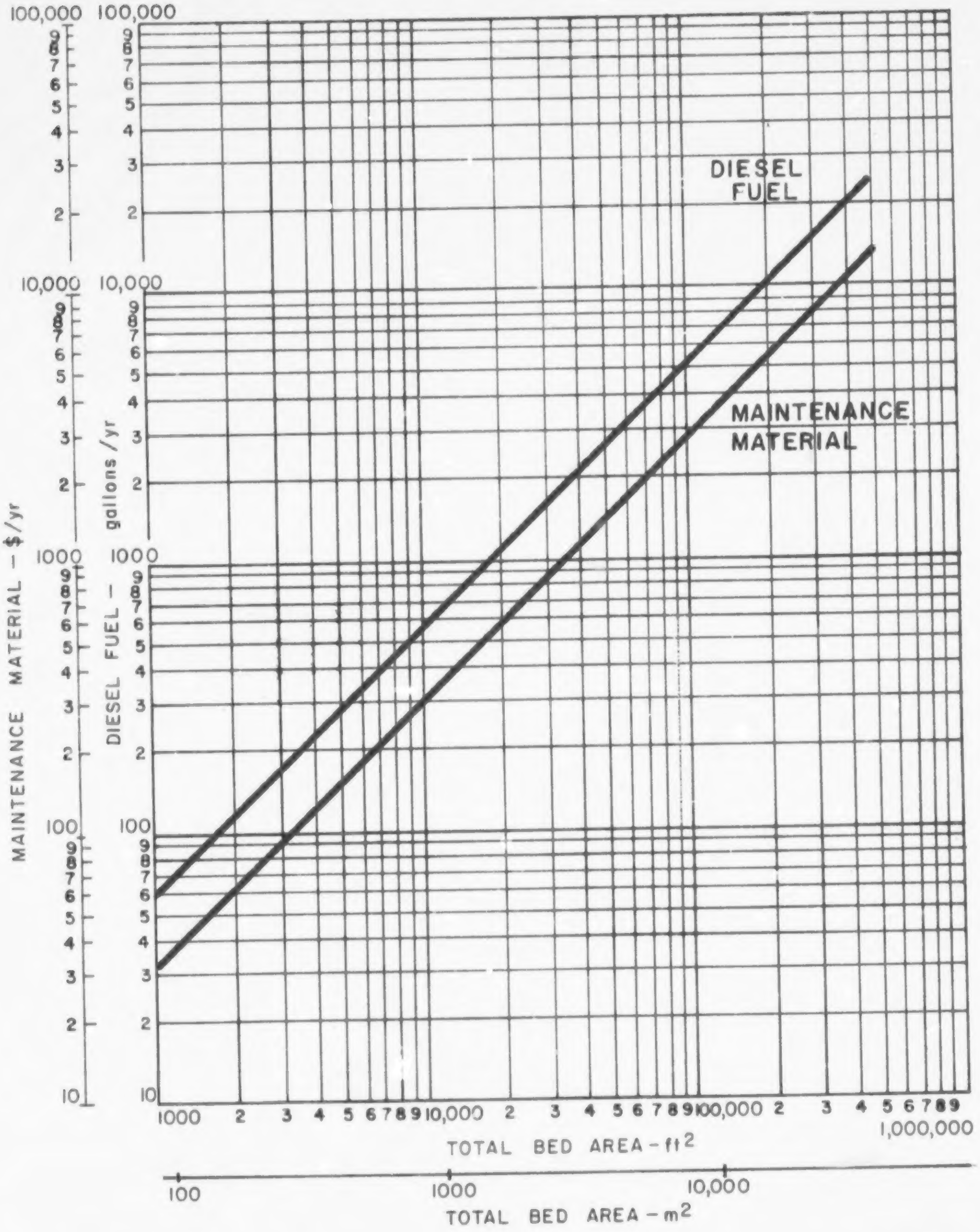


Figure 189. Operation and maintenance requirements for sand drying beds - diesel fuel and maintenance material.

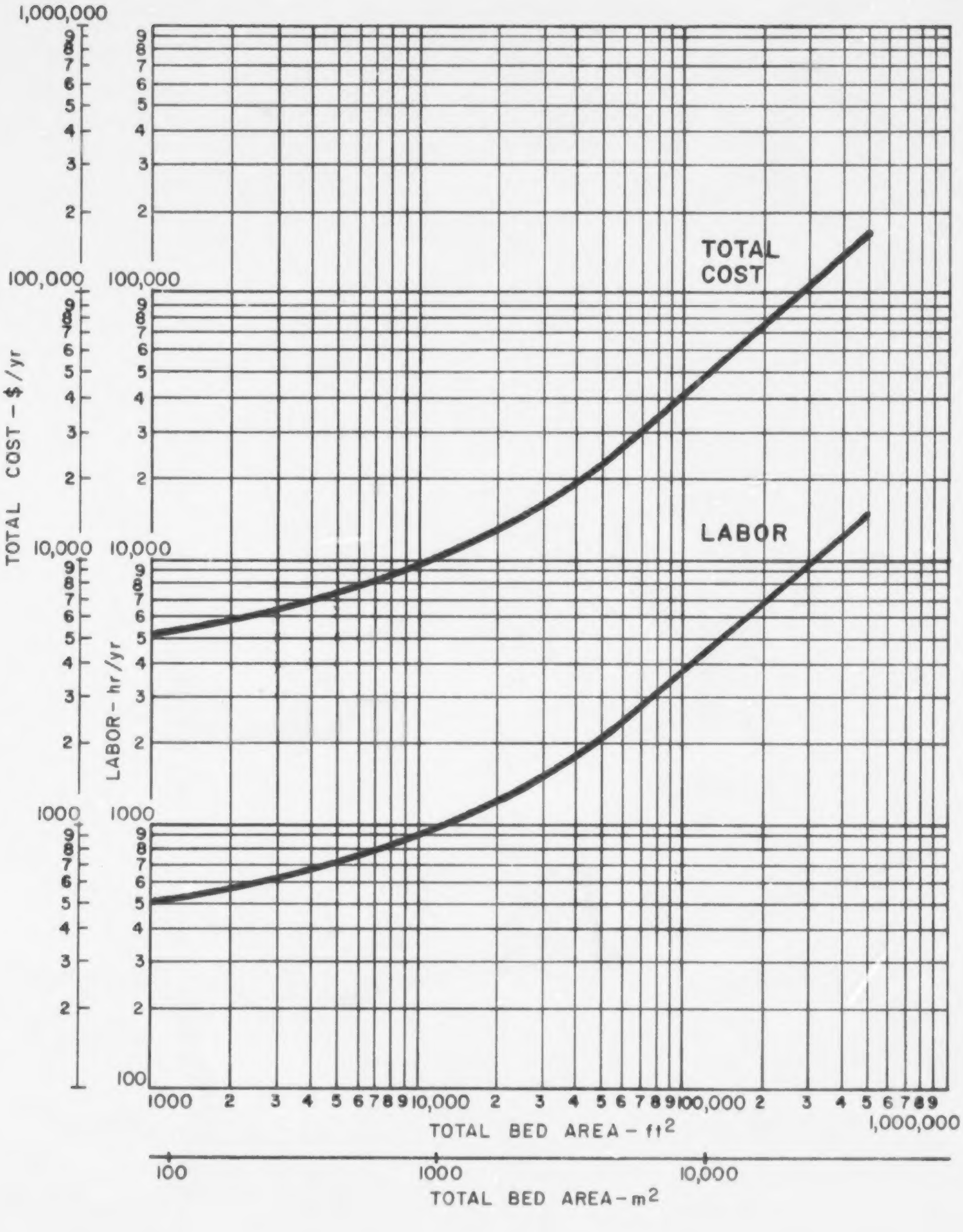


Figure 190. Operation and maintenance requirements for sand drying beds - labor and total cost.

Table 159

Operation and Maintenance Summary for Sand Drying Beds

Total Sand Drying Bed Area (ft^2)	Diesel Fuel (gal/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
5,000	300	$150	700	$7,290
10,000	600	310	900	9,580
50,000	3,000	1,540	2,100	23,890
100,000	6,000	3,090	4,000	45,790
400,000	24,000	12,340	16,000	183,140

*Calculated using $0.45/gallon for diesel fuel and $10.00/hr for labor.

BELT FILTER PRESS

Construction Cost

The belt filter press is applicable for dewatering sludge from water treatment plants and it can produce a sludge with a consistency suitable for land disposal. The belt filter press combines features of both the vacuum filter and the pressure filter, and under certain conditions it offers advantages over either of these two methods of sludge dewatering.

Construction costs were developed for belt filter press dewatering systems that included the belt press unit, wash pump, conditioning tank, feed pump, polymer storage tank and pump, belt conveyor, and electrical control panel. A typical installation is illustrated in Figure 191. Machines are generally sized using metric dimensions and are rated on the basis of sludge flow in gpm/m of belt width. For water treatment sludges, a value of 15 gpm/m of belt width is the manufacturers' loading recommendation. Table 160 provides conceptual design information and assumptions utilized for belt filter press systems with sludge handling capacities between 15 and 450 gpm.

Estimated construction costs are presented in Table 161 and shown graphically as a function of total installed machine capacity in Figure 192.

Operation and Maintenance Cost

Process energy requirements were developed from the total connected horsepower for the belt drive unit, belt wash pump, conditioning tank, feed pump, polymer pump and tanks, belt conveyor, and electrical control panel. A feed concentration of 1 percent alum sludge and a belt filter loading of 15 gpm/m of machine width was used in selecting unit sizes and determining power requirements. Twenty-two hours of continuous operation with 2 hr of downtime for routine maintenance was assumed in calculating process energy requirements.

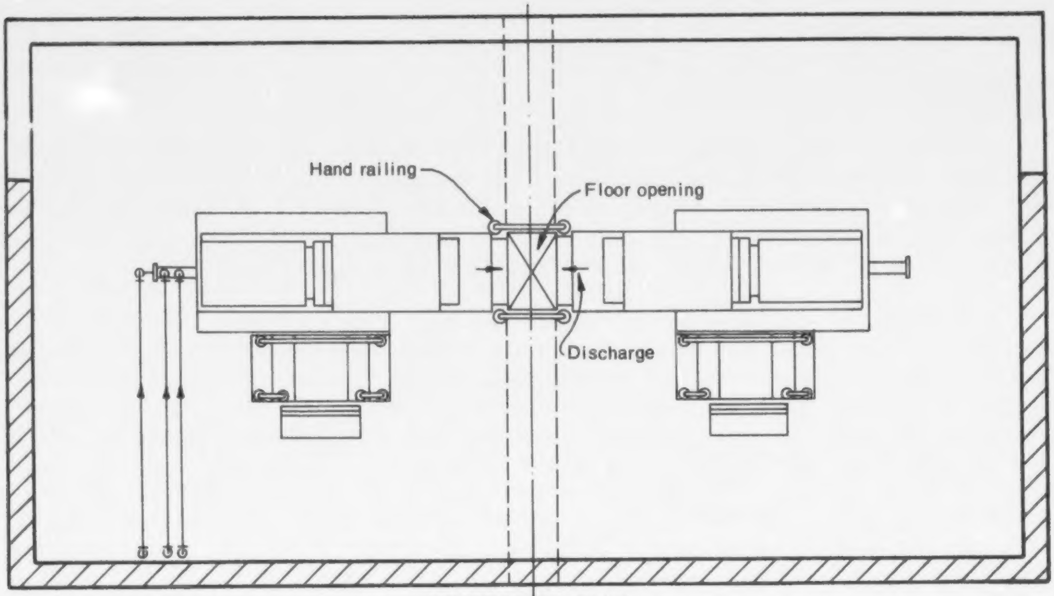
Labor and maintenance material requirements were estimated from information provided by equipment manufacturers.

Figures 193 and 194 and Table 162 present operation and maintenance requirements for the belt filter press. The assumptions used in developing these costs should be noted, as operation and maintenance costs vary widely depending on the nature and solids concentration of the sludge being processed, and adjustments may have to be made on a case-by-case basis.

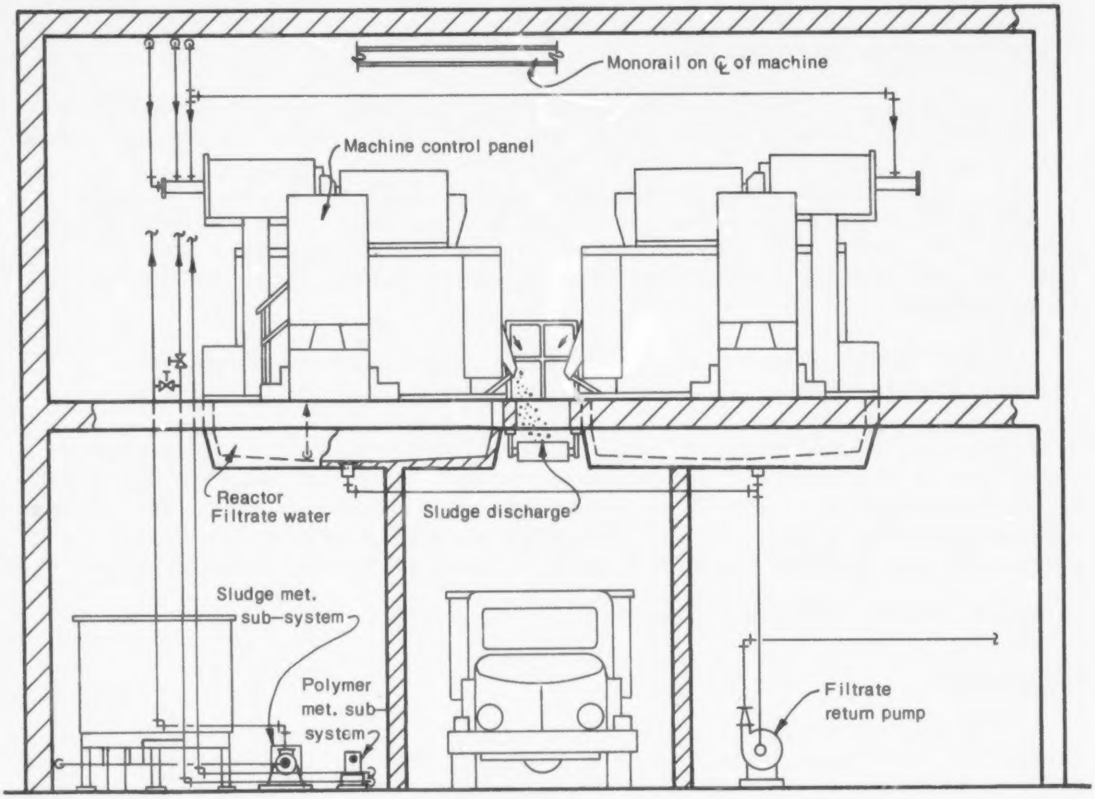
SLUDGE DISPOSAL TO SANITARY SEWERS

Annual Cost

Disposal of sludge to sanitary sewers is usually beneficial to the wastewater treatment facility, as it normally enhances sedimentation in the primary clarifiers. At the same time, however, the volume of sludge at the wastewater treatment facility increases, placing an additional load on the sludge treatment and disposal facilities.


Hand railing
Floor opening
Discharge

UPPER LEVEL PLAN


Monorail on ℄ of machine
Machine control panel
Reactor
Filtrate water
Sludge discharge
Sludge met.
sub–system
Polymer
met. sub
system
Filtrate
return pump

ELEVATION

Figure 191. Typical belt filter press installation.

Table 160

Conceptual Design for the Belt Filter Press

Total Installed Machine Capacity* (gpm)	Belt Width (m)	Number Of Units	Housing Requirements (ft^2)
15	1	1	1,100
30	2	1	1,400
225	3	6	2,800
450	3	12	5,400

*Total installed machine capacity is based on manufacturers' recommended loading of 15 gpm/m of belt width.

Table 161
Construction Cost for the
Belt Filter Press

Cost Category	Total Installed Machine Capacity (gpm)			
	15	30	225	450
Manufactured Equipment	$ 95,000	$140,000	$1,040,000	$2,000,000
Labor	28,500	42,000	310,000	600,000
Pipe and Valves	8,000	8,200	33,000	55,000
Electrical & Instrumentation	2,500	2,500	6,500	12,000
Housing	48,400	58,800	112,000	194,000
SUBTOTAL	182,400	251,500	1,501,500	2,861,000
Miscellaneous & Contingency	27,360	37,730	225,230	429,150
TOTAL COST	209,760	289,230	1,726,730	3,290,150

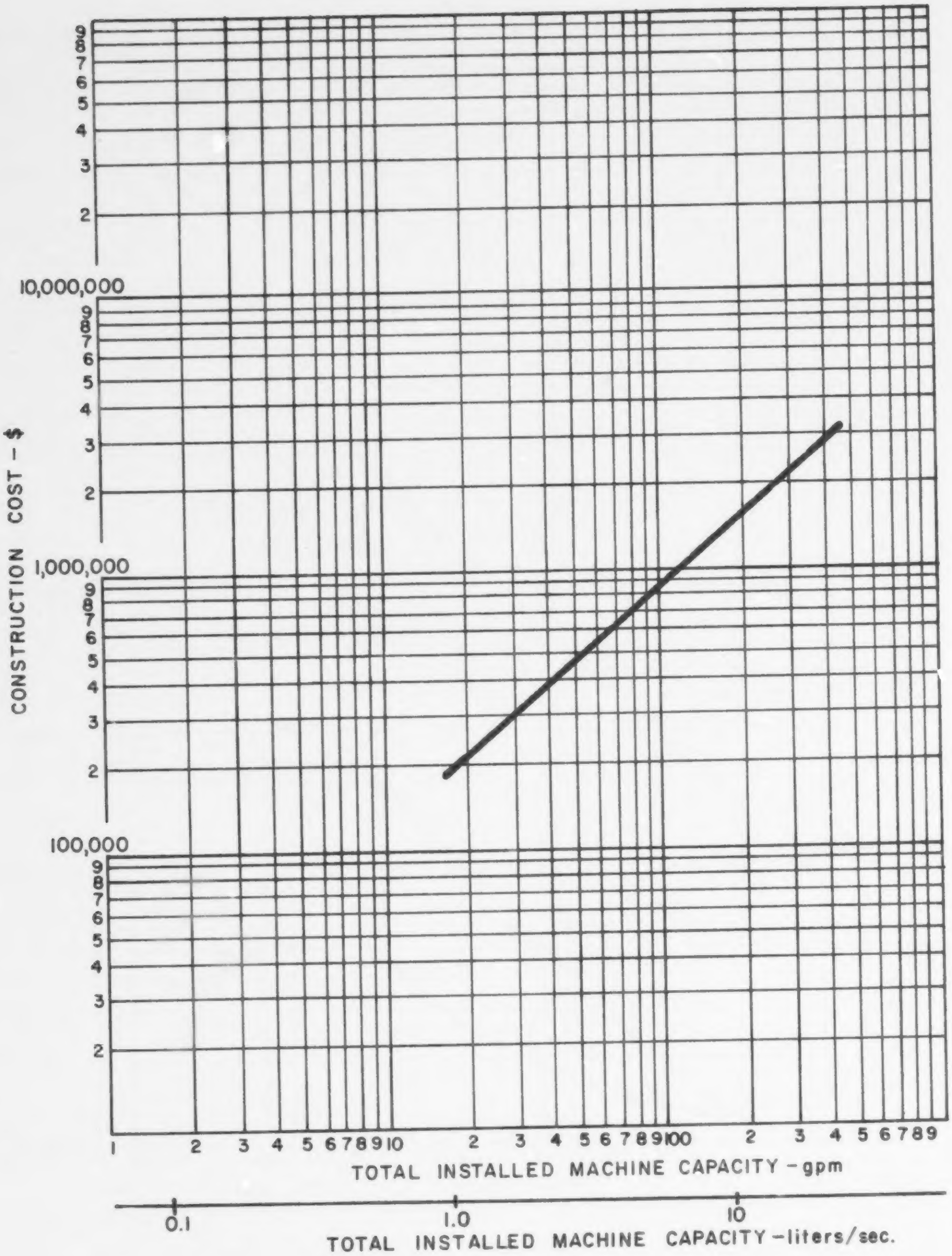


Figure 192. Construction cost for the belt filter press.

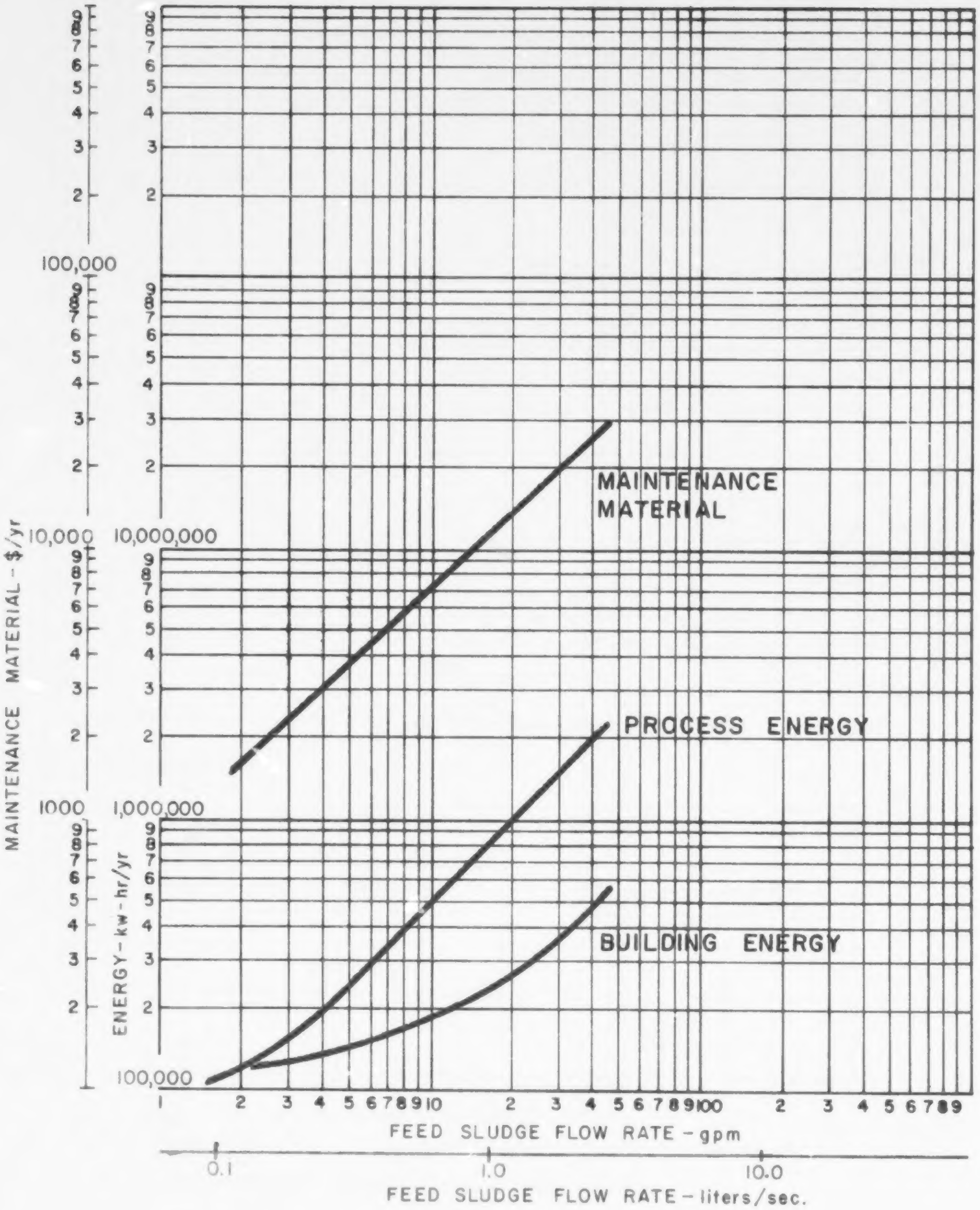


Figure 193. Operation and maintenance requirements for the belt filter press - building energy, process energy and maintenance material.

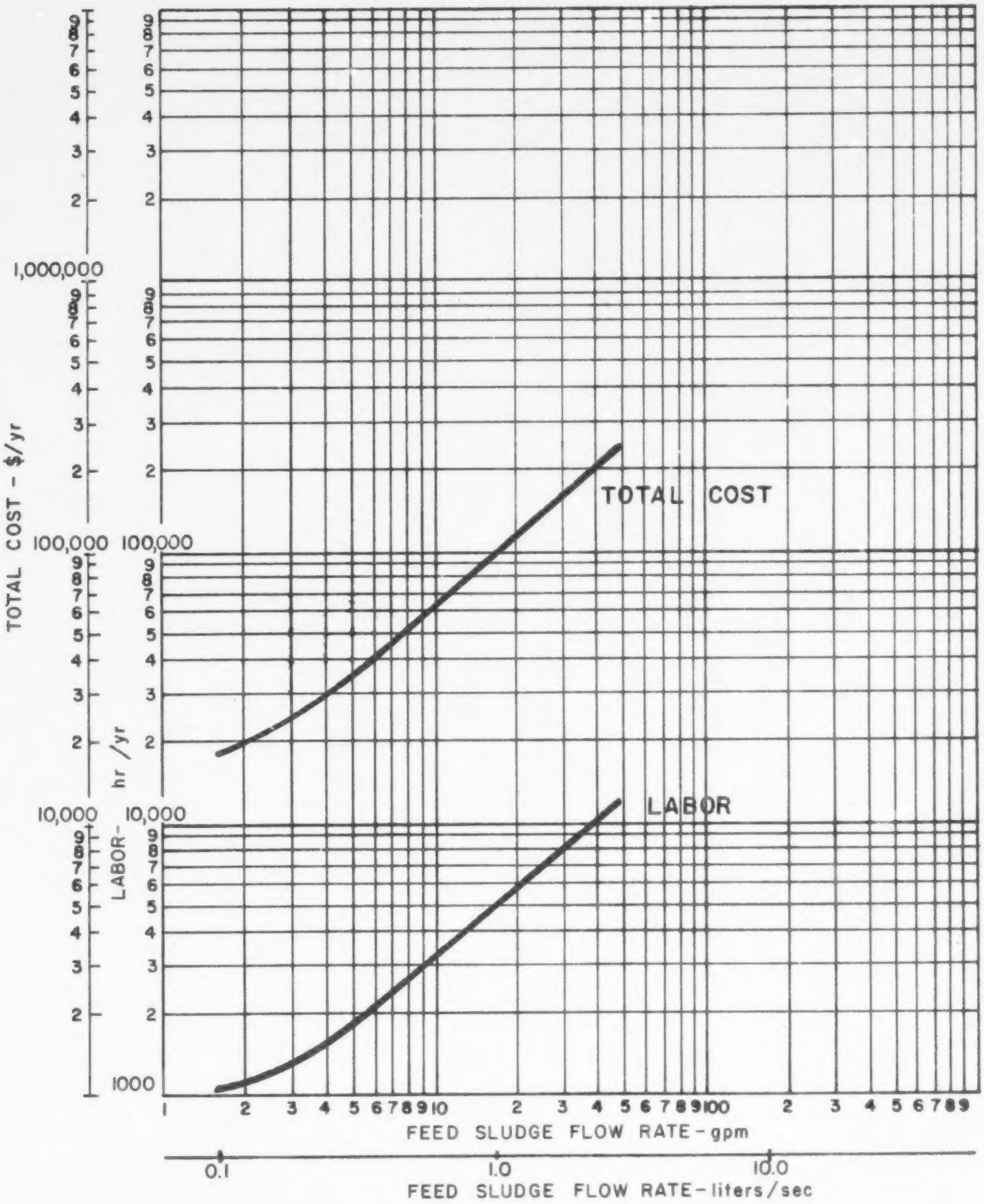


Figure 194. Operation and maintenance requirements for the belt filter press - labor and total cost.

Table 162

Operation and Maintenance Summary for the Belt Filter Press

Feed Sludge Flow Rate (gpm)	Belt Width (m)	Number of Machines	Energy (kw-hr/yr)			Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
			Building	Process	Total			
15	1	1	112,900	102,000	214,900	$1,400	1,100	$18,850
30	2	1	143,600	149,800	293,400	2,200	1,300	24,000
225	3	6	287,300	1,078,000	1,365,300	16,000	5,800	114,960
450	3	12	554,000	2,157,000	2,711,000	30,000	12,000	231,330

*Calculated using $0.03/kw-hr and $10.00/hr labor.

The cost for sludge treatment and disposal at the wastewater facility varies widely from location to location, depending on the concentration of the water treatment plant sludge, the wastewater quality, and the degree of treatment provided.

In accordance with PL 92-500, the Federal Water Pollution Control Act Amendments of 1972, most wastewater treatment agencies are implementing or have implemented revenue programs that allocate the true cost of treatment, to various categories of discharge. To estimate the cost of treating sludge from a water treatment plant, a charge of $250/million gal of wastewater was used. The wastewater was assumed to have a BOD of 225 mg/l and TSS of 275 mg/l. The $250 charge was allocated - 34 percent to flow, 33 percent to BOD, and 33 percent to suspended solids, which is equivalent to $85/million gal of flow, $0.44/lb BOD, and $0.36/lb of suspended solids. Table 163 presents the annual cost of discharging water treatment sludges with BOD values of 50 mg/l at various flow rates and suspended solids concentrations to this wastewater system. Costs are not altered significantly by sludge BOD values up to 150 mg/l. Other factors that should be considered in determining the feasibility and cost of sewer discharge are the availability of trunk sewer capacity and the cost of using this capacity.

SLUDGE HAULING TO LANDFILL OR FARMS

Construction Cost

Sludge may be conveyed to landfill or farms in a liquid form using tank trucks or in a dewatered form using dump trucks. Normally, hauling of liquid sludge would only be economical for smaller plants, whereas hauling of dewatered sludge is usually only economical for larger installations. Separate cost estimates have been made for each form of sludge hauling.

Cost estimates are based on agency ownership of the trucks and a truck usage of 8 hr/day. When other than daylight operation is possible and/or local requirements on route utilization allow operation over a 24-hr day, a substantial savings in capital expenditure will occur. Serious consideration should be given to operation over time periods greater than 8 hr/day. If such operation is possible, the costs persented must be adjusted to reflect the higher daily usage rate.

The criteria utilized to develop costs for liquid and dewatered sludge hauling are presented in Table 164.

Liquid Sludge--

Costs were developed for hauling liquid sludge with volumes ranging between 1.25 and 100 million gal/year, for one-way distances between 5 and 40 miles. All estimates were for the use of a 5,500-gal tanker truck, which is more cost effective than smaller-sized tankers. The number of trucks required and the initial capital cost for liquid sludge loading facilities are shown in Table 165. Loading facilities include a truck-loading enclosure and appropriate piping and valving to allow loading in a maximum time of 20 min. Pumping facilities are not included in these costs, as separate curves are

Table 163

Annual Cost for Sludge Disposal to Sanitary Sewers*

Sludge Volume		Suspended Solids Concentration (mg/1)				
gpm	mgd	1,000	5,000	10,000	50,000	100,000
20	0.0288	$4,240	$16,850	$32,600	$158,760	$316,440
100	0.144	21,200	84,270	163,110	793,800	1,582,200
500	0.72	106,000	421,250	815,500	3,969,000	7,911,000
1,000	1.44	212,000	842,500	1,631,000	7,938,000	--
5,000	7.20	1,060,000	4,212,500	8,155,000	--	--
10,000	14.40	2,120,000	8,425,000	--	--	--

*Costs are based on a wastewater charge of $250/million gal for wastewater with a BOD of 225 mg/1 and a suspended solids concentration of 275 mg/1. The $250/million gal charge was assumed to be allocated as follows: 34 percent to volume, 33 percent to BOD, and 33 percent to suspended solids.

Table 164

Cost-Estimating Criteria for Liquid and Dewatered Sludge Hauling*

Sludge Type	Truck Capacity	Fuel	Capital Cost	Mileage (mpg)	Fuel Cost ($/gal)	Operator Cost ($/gal)	Operation[+] Cost ($/mile)
Liquid	5,500/gal	Diesel	$ 63,240	3.5	$ 0.45	$ 15.00	$ 0.328
Dewatered	$10/yd^3$	Gas	28,750	4.5	0.55	15.00	0.219
	$30/yd^3$	Diesel	57,490	3.5	0.45	15.00	0.328

[+] Operation cost excludes operator and fuel cost.

*Note: The following transport cycling criteria were also utilized :

Loading time - 20 min/truck
Unloading time - 15 min/truck
Speed - 25 mph for 1st 20 miles of one-way distance
35 mph for more than 20 miles of one-way distance

Table 165

Initial Construction Cost for Liquid Sludge Hauling

Annual Volume of Sludge (million gal/yr)	One Way Haul Distance miles	Number of Trucks Required	Initial Cost of Trucks	Construction Cost of Loading Facilities	Total Initial Cost
1.25	5	1	$ 63,240	$ 15,500	$ 78,740
	20	1	63,240	15,500	78,740
	40	1	63,240	15,500	78,740
5.0	5	1	63,240	15,500	78,740
	20	1	63,240	15,500	78,740
	40	2	126,480	15,500	141,980
20	5	2	126,480	15,500	141,980
	20	4	252,960	15,500	268,460
	40	6	379,440	15,500	394,940
50	5	4	252,960	31,000	283,960
	20	9	569,160	31,000	600,160
	40	13	822,120	31,000	853,120
100	5	8	505,920	46,500	552,420
	20	17	1,075,080	46,500	1,121,580
	40	26	1,644,240	62,000	1,706,240

provided for chemical sludge pumping. The initial capital costs are illustrated in Figure 195.

Dewatered Sludge--

Costs were also developed for hauling dewatered sludge with volumes of 1,000 to 300,000 yd^3/year over one-way distances between 5 and 40 miles. Loading facilities include a sludge conveyor, a hopper capable of holding 1.5 truckloads of sludge, and an enclosure for the sludge hopper. When more than one hopper was required, multiple conveyors and enclosures were utilized. The initial capital cost for loading facilities and trucks is shown in Table 166 and Figure 196.

Operation and Maintenance Cost

Energy requirements for sludge hauling are for diesel fuel. The mileage estimates utilized for various truck configurations used in the cost estimates are shown in Table 164. Process energy for sludge pumping at the treatment facility is not included; the cost curves for chemical sludge pumping should be utilized if pumping is required.

Maintenance costs for the trucks were calculated on a $/mile-traveled basis, using the per-mile costs included in Table 164. The maintenance costs do not include fuel.

Labor requirements are for the truck operators. A loading time of 20 min and an unloading time of 15 min were utilized, and it was assumed that the truck operator would be responsible for each.

Operation and maintenance costs for liquid sludge hauling are presented in Table 167 and in Figures 197 and 198. Dewatered sludge hauling operation and maintenance costs are presented in Table 168 and in Figures 199 and 200.

RAW WATER PUMPING FACILITIES

Construction Cost

Costs were developed for raw water pumping facilities, but the costs exclude a wet well and housing, since these requirements will be extremely variable from location to location. The costs include pumps, valves and manifold piping, and electrical equipment and instrumentation. Pumps were constant speed vertical turbine type, driven by drip-proof, high-thrust vertical motors. A standby pump equal in capacity to the largest pump was also included. Manifold piping was sized for a velocity of 5 ft/second.

Estimated construction costs are shown in Table 169 for pumping against TDH of 30 and 100 ft. The costs are also presented in Figure 201.

Operation and Maintenance Cost

Process energy requirements were calculated for 30 and 100-ft TDH, using a motor efficiency of 90 percent and a pump efficiency of 85 percent.

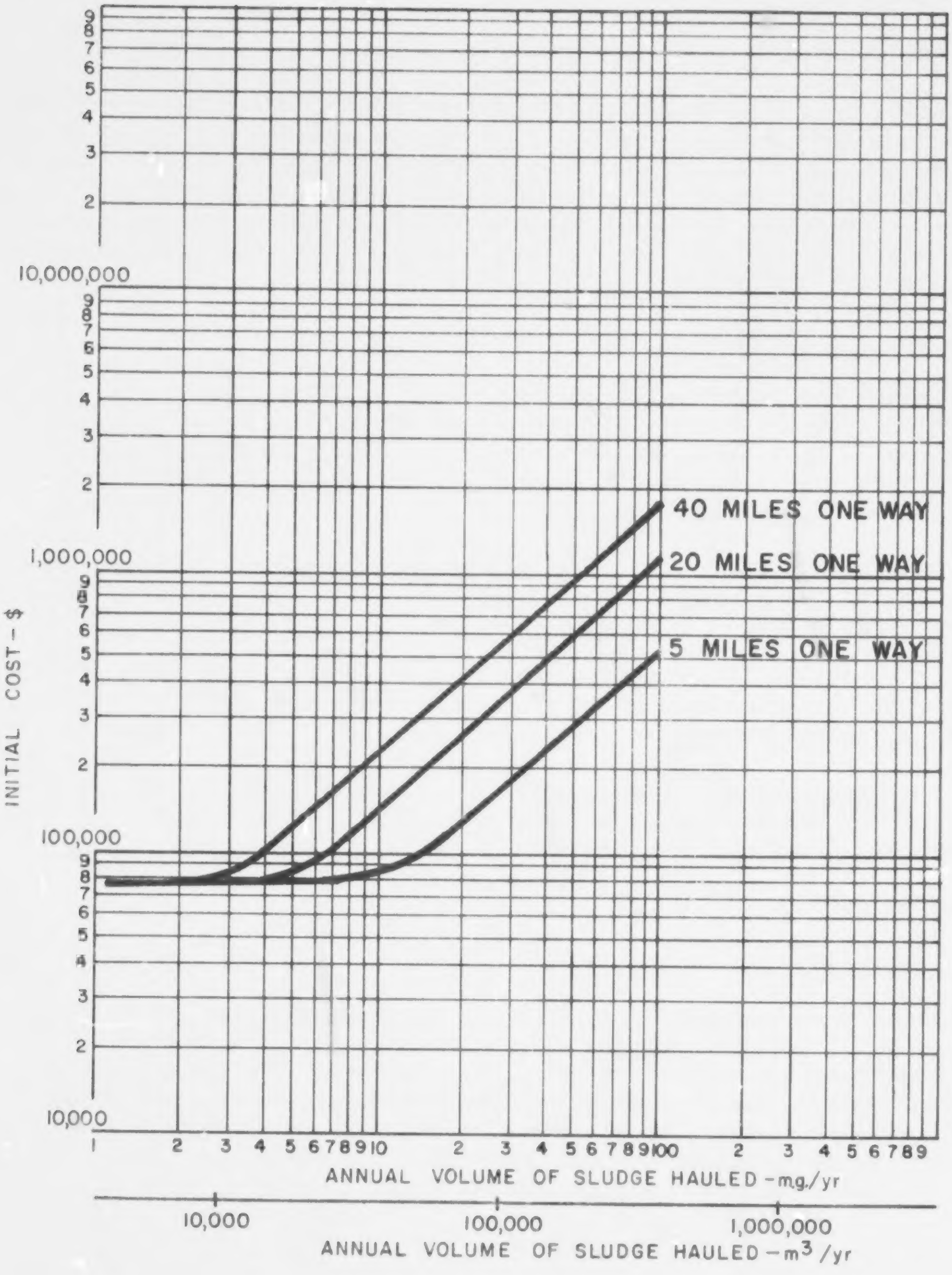


Figure 195. Initial construction cost for liquid sludge handling - 5-, 20-, and 40-mile haul distances.

Table 166

Initial Capital Cost for Dewatered Sludge Hauling

Annual Volume of Sludge (yd^3/yr)	One-Way Haul Distances (miles)	Size of Trucks (yd^3)	Initial Cost of Trucks	Construction Cost of Loading Facilities	Total Initial Cost
1,000	5	10	$ 28,750	$ 15,900	$44,650
	20	10	28,750	15,900	44,650
	40	10	28,750	15,900	44,650
10,000	5	30	57,490	32,800	90,290
	20	30	57,490	32,800	90,290
	40	30	57,490	32,800	90,290
50,000	5	30	57,490	32,800	90,290
	20	30	114,980	32,800	147,780
	40	30	172,470	48,700	221,170
150,000	5	30	114,980	32,800	147,780
	20	30	287,450	48,700	336,150
	40	30	402,430	65,600	468,030
300,000	5	30	229,960	65,600	295,560
	20	30	574,900	81,500	656,400
	40	30	804,860	114,300	919,160

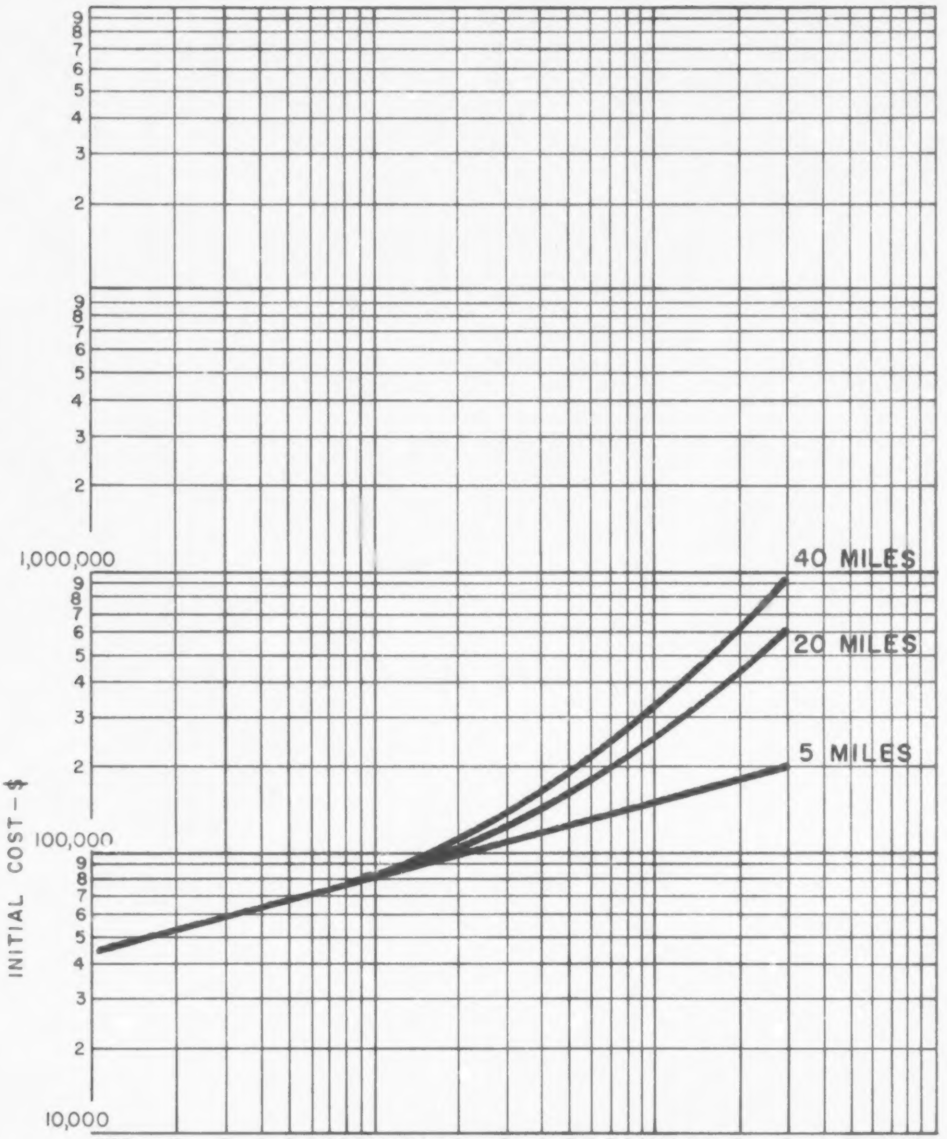


Figure 196. Initial construction cost for dewatered sludge hauling-5-, 20-, and 40-mile haul distances.

Table 167

Operation and Maintenance Summary for Liquid Sludge Hauling

Annual Volume of Sludge (million gal/yr)	One-Way Haul Distances (miles)	Diesel Fuel (gal/yr)	Maintenance ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1.25	5	700	$ 750	260	$ 4,970
	20	2,600	2,980	540	12,250
	40	5,200	5,980	790	20,170
5	5	2,600	2,980	1,045	19,830
	20	10,400	11,940	2,140	48,720
	40	20,800	23,850	3,160	80,610
20	5	10,400	11,940	4,180	79,320
	20	41,600	47,560	8,540	194,380
	40	83,100	95,420	12,650	322,570
50	5	26,000	29,820	10,455	198,350
	20	104,000	119,260	21,360	486,460
	40	208,000	238,520	31,640	806,720
100	5	51,900	59,630	20,910	396,640
	20	207,600	238,520	42,730	972,890
	40	415,200	477,040	63,270	1,612,930

*Calculated using $0.45/gal of diesel fuel and $15/hr of labor.

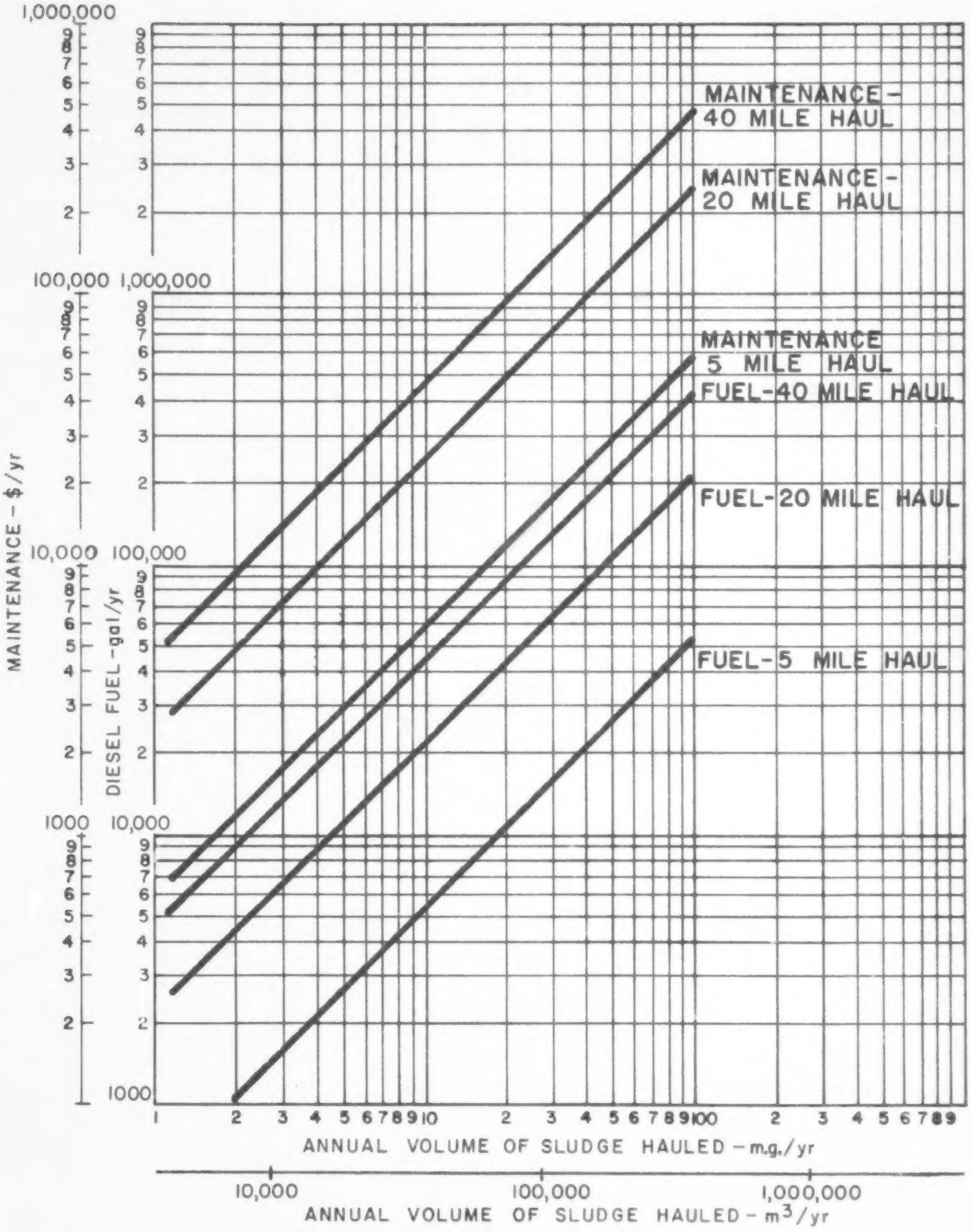


Figure 197. Operation and maintenance requirements for liquid sludge hauling - diesel fuel and maintenance material needed for 5-, 20-, and 40-mile haul distances.

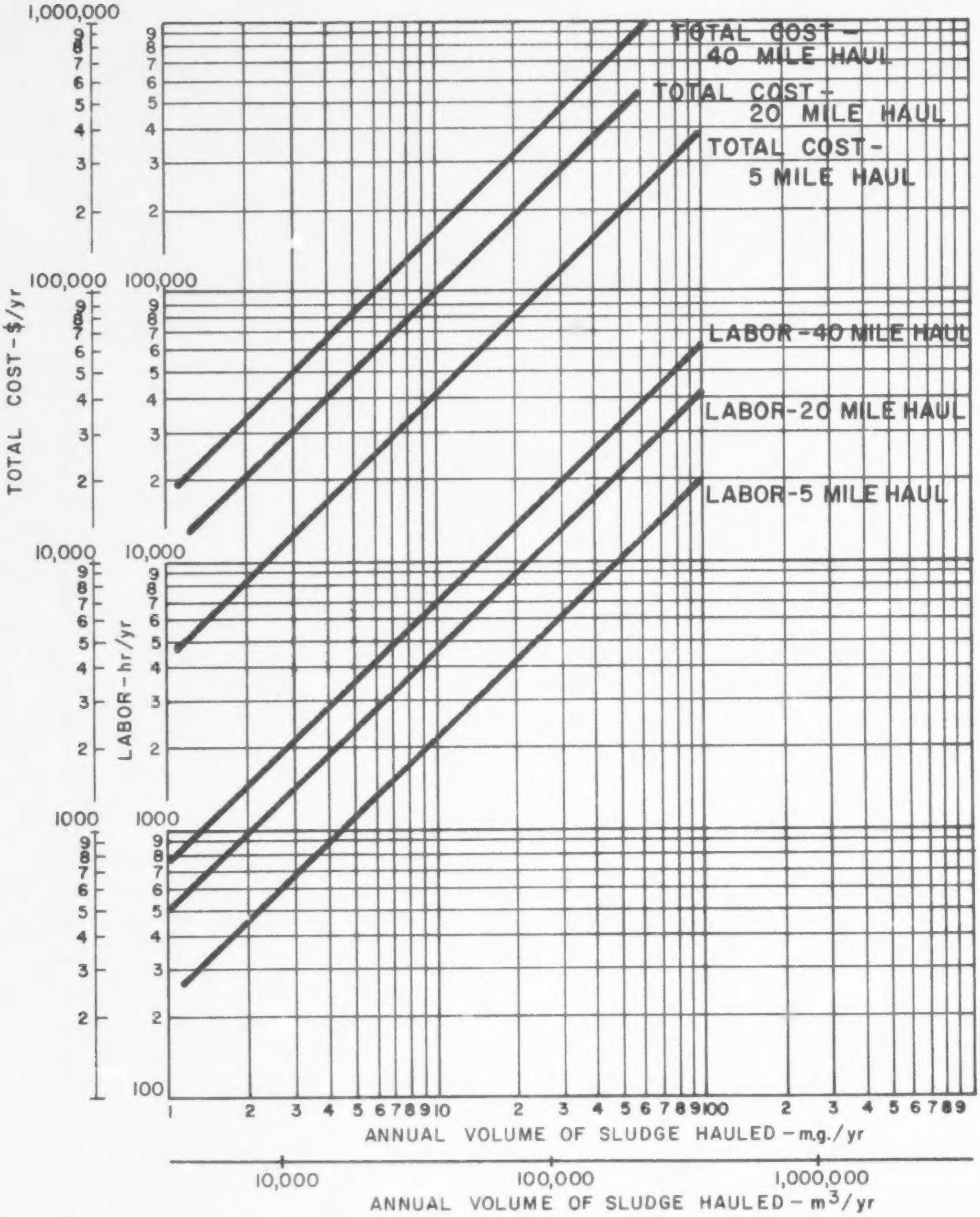


Figure 198. Operation and maintenance requirements for liquid sludge hauling - labor and total cost needed for 5-, 20-, and 40-mile haul distances.

Table 168

Operation and Maintenance Summary for Dewatered Sludge Hauling

Annual Volume of Sludge (yd^3/yr)	One-Way Haul Distance (miles)	Diesel Fuel (gal/yr)	Maintenance ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1,000	5	220	$ 220	120	$ 2,120
	20	890	880	240	4,880
	40	1,700	1,750	350	7,770
10,000	5	1,000	1,090	380	7,240
	20	3,800	4,370	780	17,780
	40	7,600	8,740	1,200	30,160
50,000	5	4,900	5,470	1,900	36,180
	20	19,100	21,870	3,900	88,970
	40	38,000	43,740	5,800	147,840
150,000	5	14,300	16,400	5,900	111,340
	20	57,100	65,600	11,800	268,300
	40	114,300	131,200	17,400	443,640
300,000	5	28,600	32,800	11,500	218,170
	20	114,300	131,200	23,500	535,140
	40	228,600	262,400	34,800	887,270

*Calculated using $0.45/gal of diesel fuel and $15/hr of labor.

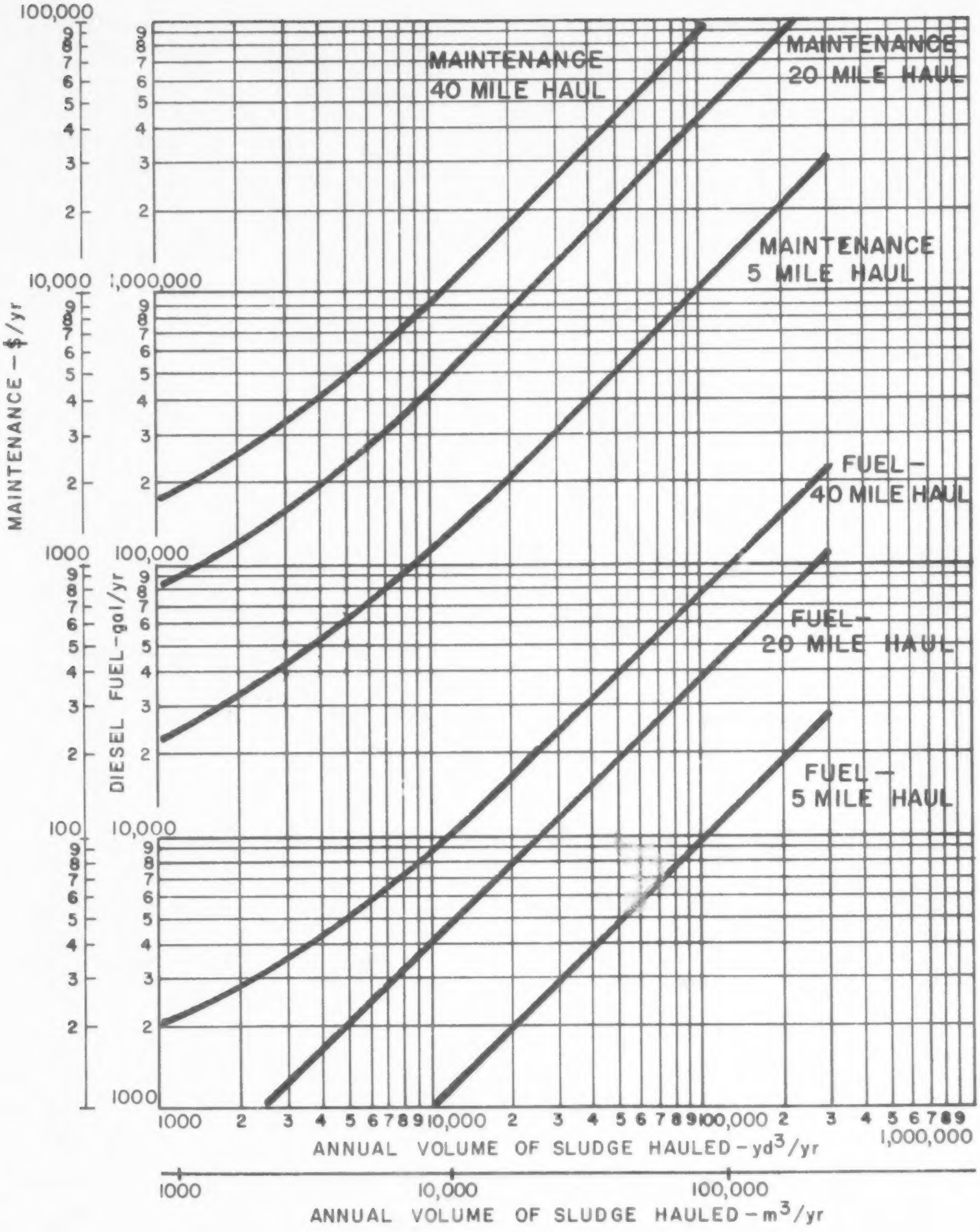


Figure 199. Operation and maintenance requirements for dewatered sludge hauling - fuel and maintenance material needed for 5-, 20-, and 40-mile haul distances.

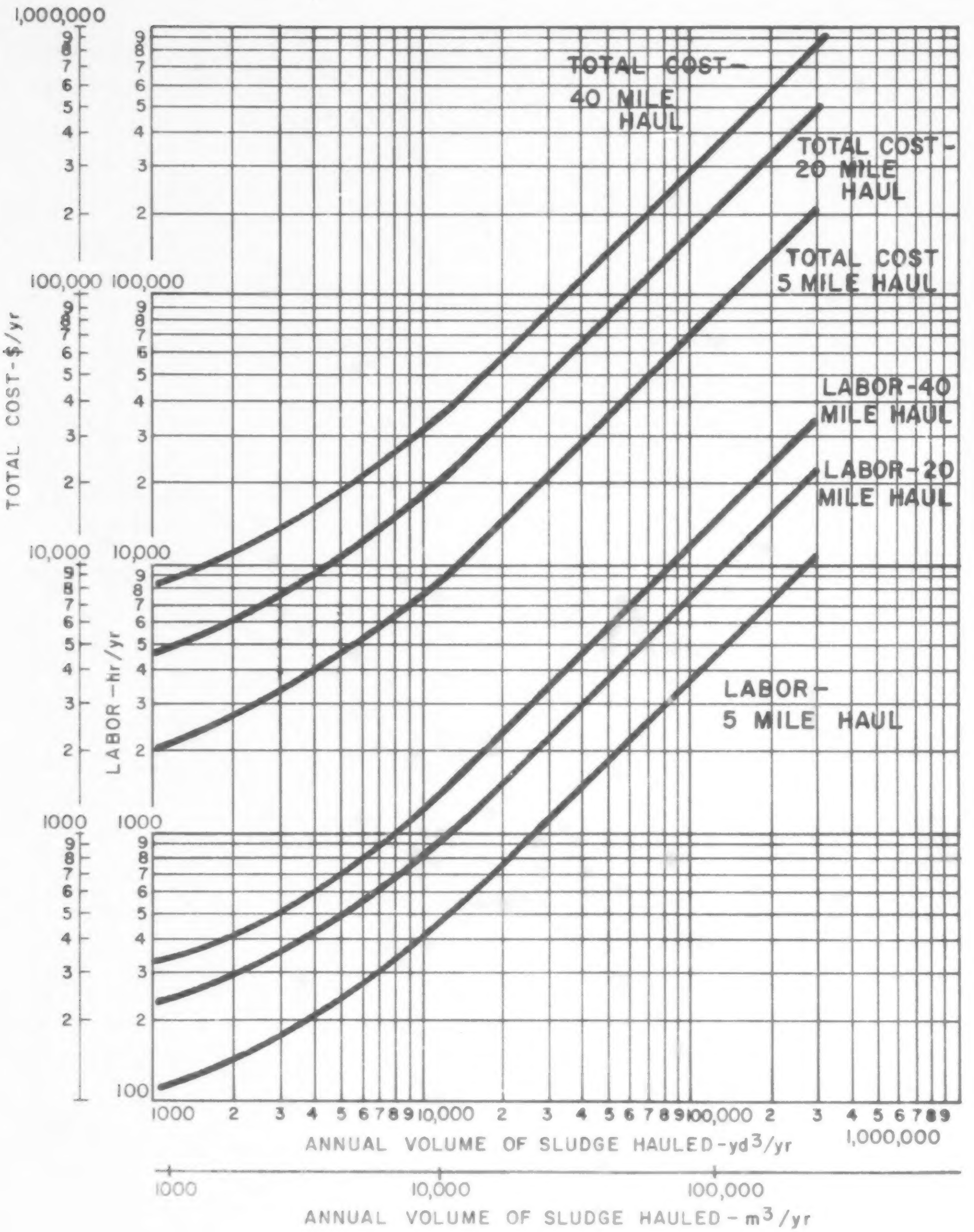


Figure 200. Operation and maintenance requirements for dewatered sludge hauling - labor and total cost needed for 5-, 20-, and 40-mile haul distances.

Table 169

Construction Cost for

Raw Water Pumping Facilities

Cost Category	Plant Capacity							
	1 mgd		10 mgd		100 mgd		200 mgd	
	30-ft TDH	100-ft TDH	30-ft TDH	100-ft TDH	30-ft TDH	100-ft TDH	30-ft TDH	100-ft TDH
Manufactured Equipment	$ 7,890	$8,680	$17,880	$30,150	$127,600	$192,270	$243,600	$367,060
Labor	3,510	3,650	8,200	8,770	50,060	53,030	96,460	102,130
Pipe and Valves	5,090	5,090	16,300	16,300	97,550	97,550	186,770	186,770
Electrical & Instrumentation	3,060	3,860	4,620	8,470	26,160	93,240	52,770	192,270
SUBTOTAL	19,550	21,280	47,000	63,690	301,370	436,090	580,600	848,230
Miscellaneous & Contingency	2,930	3,190	7,050	9,550	45,210	65,410	87,090	127,230
TOTAL	22,480	24,470	54,050	73,240	346,580	501,500	667,690	975,460

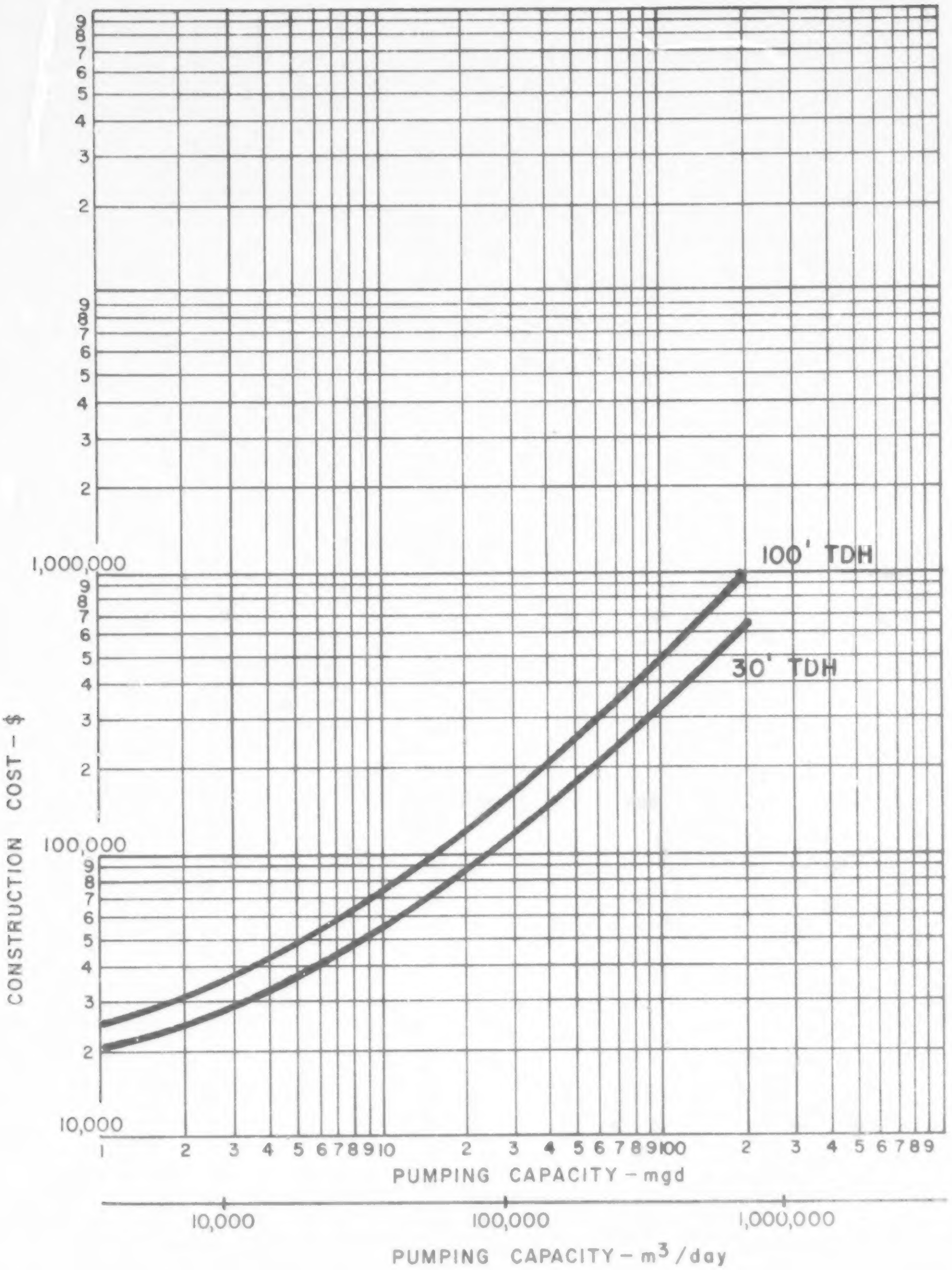


Figure 201. Construction cost for raw water pumping facilities.

Maintenance material includes repair parts for pumps and motors, valves, and electrical starters and controls.

Labor requirements are based on operation and maintenance of the pumps, motors, and valving, plus maintenance of electrical controls.

Figures 202 and 203 present operation and maintenance requirements, and Table 170 summarizes these requirements.

FINISHED WATER PUMPING FACILITIES

Construction Cost

Depending on distribution system layout and storage, finished water pumping requirements may be greater than the average daily plant flow. To account for such variations in capacity of the finished water pumping facilities, costs were developed for facilities with a capacity range between 1.5 and 300 mgd. Pumps utilized were the vertical turbine type driven by 1,800 rpm, constant speed, drip proof, high thrust, vertical motors. One standby pump with capacity equal to the largest pump was also provided.

The costs include all electrical equipment and instrumentation as well as valving and manifolding within the pumping station. Manifold piping was sized for a velocity of 5 ft/second. No costs are included for housing or a wetwell, as it was assumed that the clearwell would serve as the wetwell. Separate cost curves are provided for clearwell storage.

Figure 204 and Table 171 present the construction costs for finished water pumping facilities.

Operation and Maintenance Cost

Process energy requirements were calculated for 100 and 300-ft TDH using a motor efficiency of 90 percent and a pump efficiency of 85 percent. Maintenance material includes repair parts for pumps, motors, valves, and electrical starters and controls.

Labor requirements are based on operation and maintenance of the pumps, motors, and valving, plus maintenance of electrical controls.

Figures 205 and 206 present operation and maintenance requirements, and Table 172 summarizes these requirements.

CLEARWELL STORAGE

Construction Cost

Product water is commonly stored at the plant site before high-service pumping, as a supplement to distribution system storage. In many cases, filter or granular activated carbon wash water pumps also draw from the clearwell, eliminating the need for a separate sump. Clearwell storage may be either below ground in reinforced concrete structures, or above ground

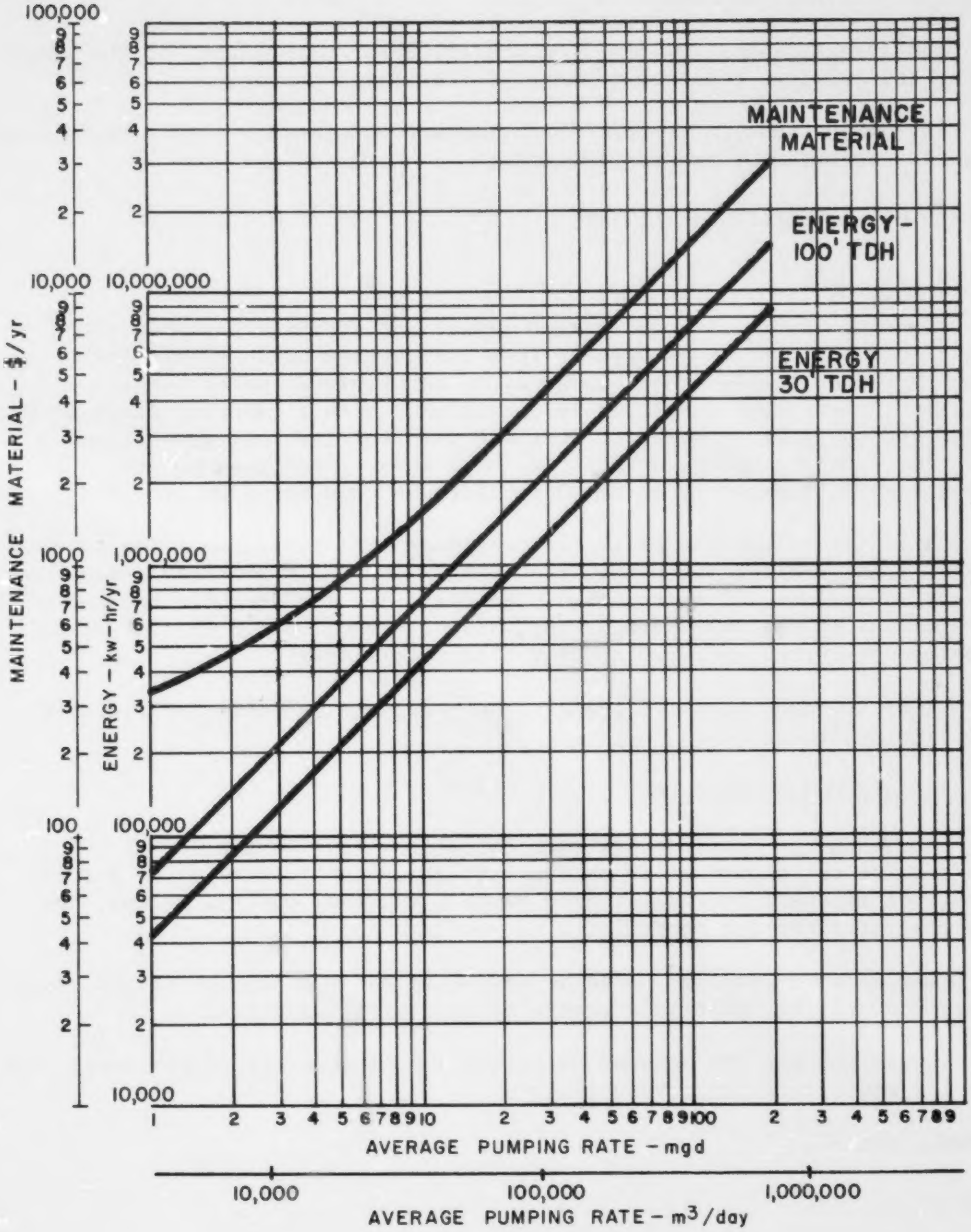


Figure 202. Operation and maintenance requirements for raw water pumping facilities - process energy and maintenance material needed for 30- and 100-ft TDH.

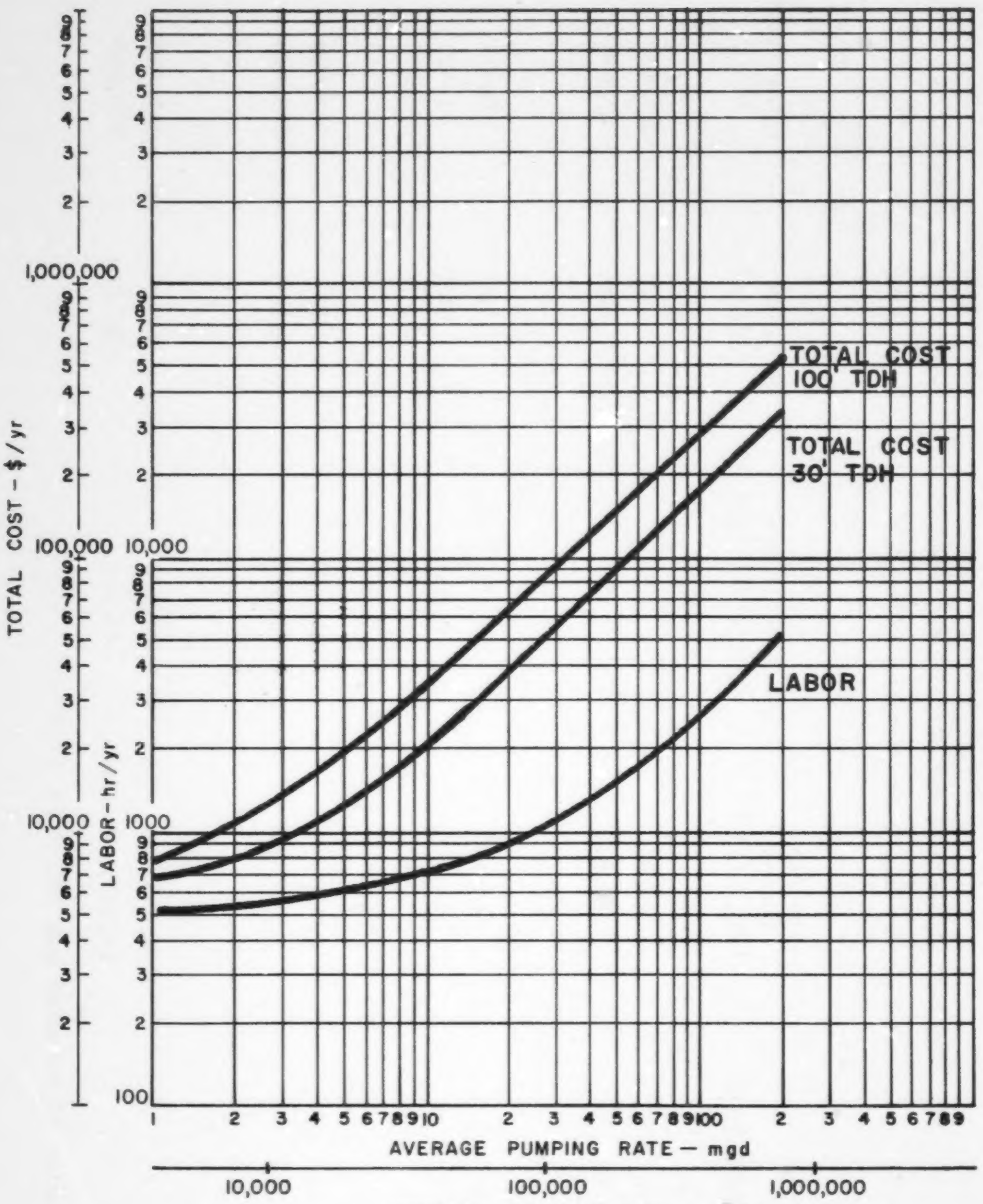


Figure 203. Operation and maintenance requirements for raw water pumping facilities - labor and total cost for 30- and 100-ft TDH.

Table 170

Operation and Maintenance Summary for Raw Water Pumping Facilities

Capacity/Pumping Head	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1 mgd :				
30 ft	44,940	$ 350	520	$ 6,900
100 ft	74,930	350	520	7,800
10 mgd:				
30 ft	449,420	1,600	740	22,480
100 ft	749,260	1,600	740	31,490
100 mgd:				
30 ft	4,494,240	15,000	2,690	176,800
100 ft	7,492,580	15,000	2,690	266,680
200 mgd:				
30 ft	8,988,490	25,000	5,130	345,950
100 ft	14,985,170	25,000	5,130	525,860

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

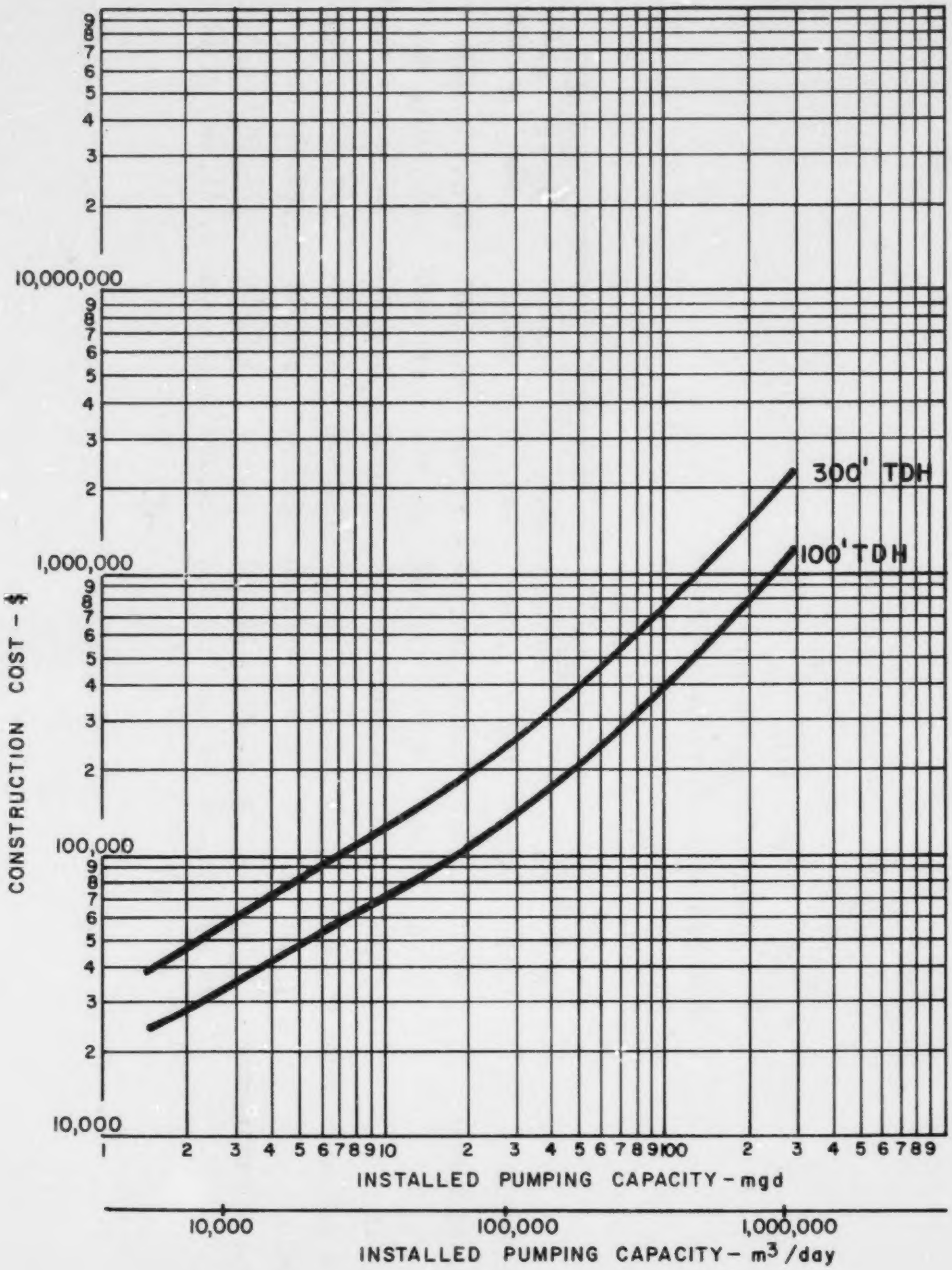


Figure 204. Construction cost for finished water pumping facilities - 100- and 300-ft TDH.

Table 171

Construction Cost for Finished Water Pumping Facilities

Cost Category	Plant Capacity							
	1.5 mgd		15 mgd		150 mgd		300 mgd	
	30-ft TDH	100-ft TDH	30-ft TDH	100-ft TDH	30-ft TDH	100-ft TDH	30-ft TDH	100-ft TDH
Manufactured Equipment	$ 9,260	$15,410	$35,630	$89,700	$259,000	$567,600	$501,810	$1,142,350
Labor	3,310	3,880	9,180	11,580	66,950	80,400	104,360	158,840
Pipe and Valves	5,200	5,200	16,570	16,570	139,200	139,200	270,100	270,100
Electrical & Instrumentation	3,340	7,180	14,120	38,450	164,640	210,490	290,320	400,230
SUBTOTAL	21,110	31,670	75,500	156,300	629,790	997,690	1,166,590	1,971,520
Miscellaneous & Contingency	3,170	4,750	11,330	23,450	94,470	149,650	174,990	295,730
TOTAL	24,280	36,420	86,830	179,750	724,260	1,147,340	1,341,580	2,267,250

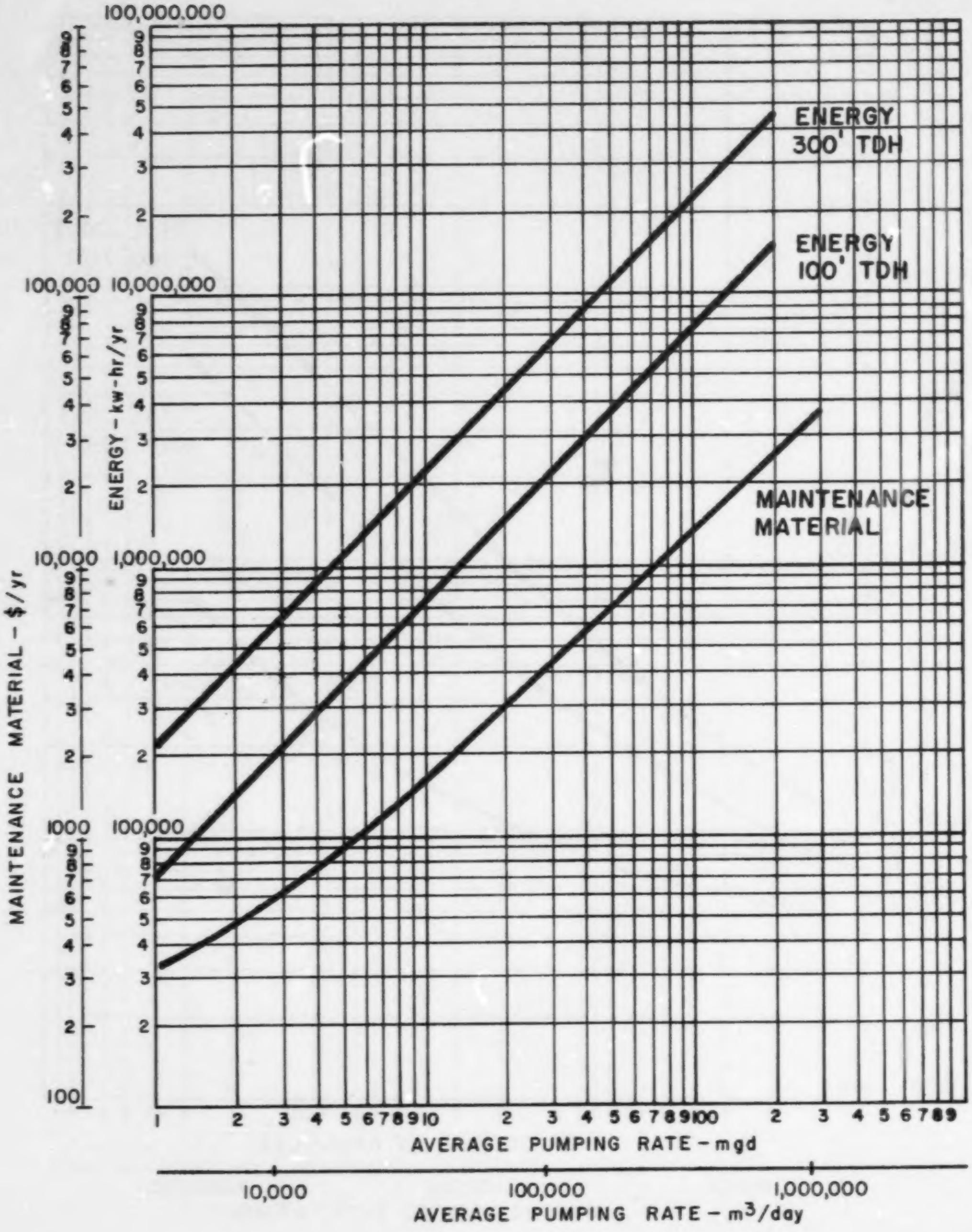


Figure 205. Operation and maintenance requirements for finished water pumping facilities - process energy and maintenance material for 100- and 300-ft TDH.

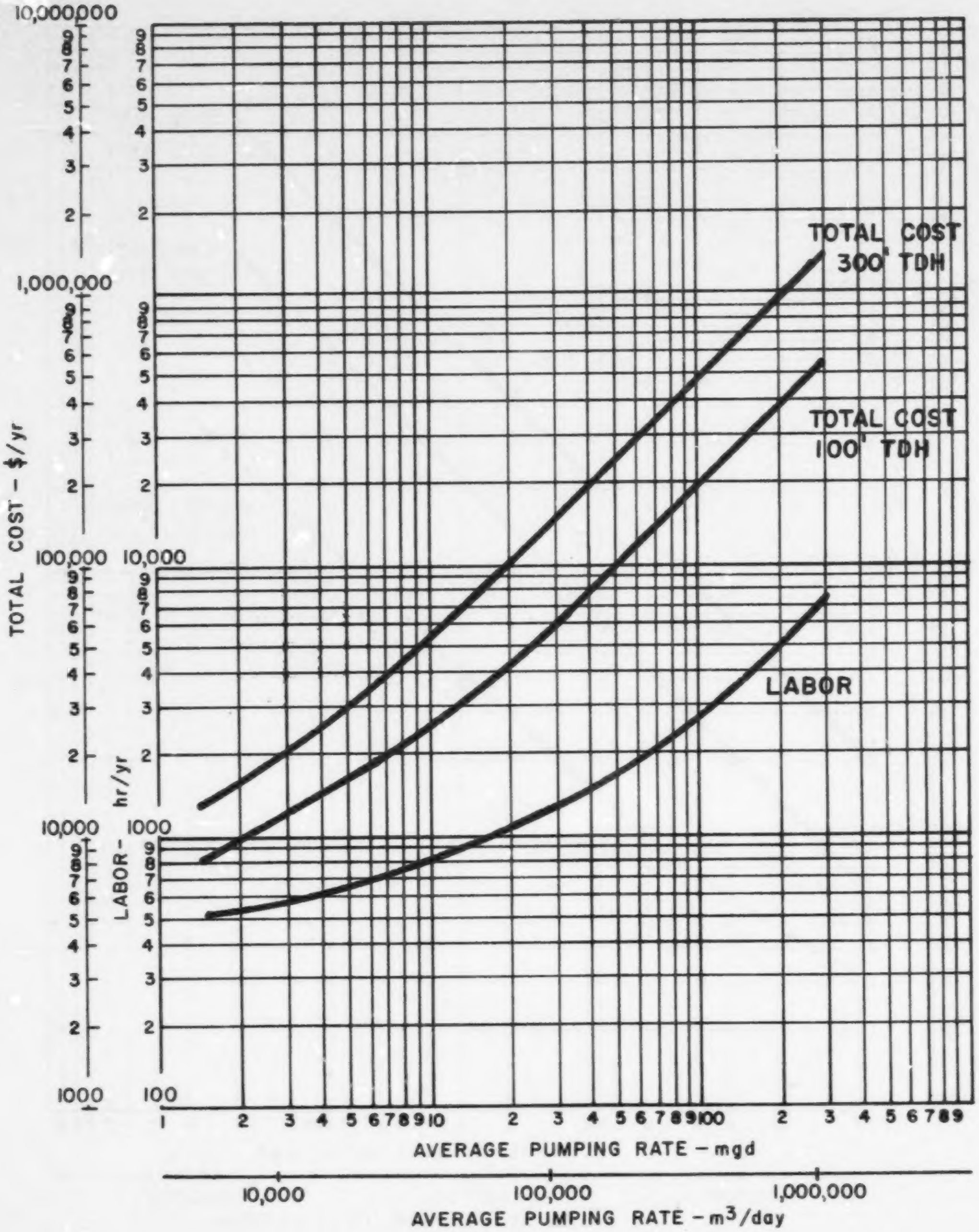


Figure 206. Operation and maintenance requirements for finished water pumping facilities - labor and total cost for 100- and 300-ft TDH.

Table 172

Operation and Maintenance Summary for Finished Water Pumping Facilities

Capacity/Pumping Head	Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1.5 mgd :				
100 ft	74,930	$ 410	534	$ 8,000
300 ft	224,790	410	534	13,090
15 mgd :				
100 ft	749,260	2,380	843	33,290
300 ft	2,247,780	2,380	843	78,240
150 mgd :				
100 ft	7,492,580	20,000	3,910	283,880
300 ft	22,477,740	20,000	3,910	733,430
300 mgd :				
100 ft	14,985,170	37,500	7,690	563,960
300 ft	44,955,510	37,500	7,690	1,463,070

*Calculated using $0.03/kw-hr and $10.00/ hr of labor.

in steel tanks. Instrumentation and control of the clearwell water level is very important in terms of pacing the plant output. In addition, instrumentation for turbidity and chlorine measurement, as well as other quality control operations, is normally provided with the clearwell. Conceptual designs for below and above-ground-level clearwells are shown in Table 173.

Table 173

Conceptual Designs for Clearwell Storage

Below-Ground Clearwells				Ground-Level Clearwells		
	Size (ft)				Size (ft)	
Capacity (gal)	Length	Width	Depth	Capacity (gal)	Diameter	Depth
10,000	11	11	12	8,500	12	10
50,000	18	18	20	37,600	20	16
100,000	26	26	20	88,100	25	24
500,000	58	58	20	475,900	45	40
1,000,000	82	82	20	846,000	60	40
7,500,000	224	224	20	4,606,200	140	40
				9,400,400	200	40

Construction costs are shown in Table 174 for below-ground clearwells and in Table 175 for ground-level clearwells. Figure 207 presents the costs for both types of clearwells.

AERATION

Construction Cost

Aeration is a useful technique for the removal of TTHM and other volatile organic compounds from water, as well as for the oxidation of iron and manganese compounds. Two techniques are available - diffused aeration basins and/or aeration towers. These techniques are discussed individually in the following sections.

Diffused Aeration Basins--

Costs were developed for open, reinforced concrete basins with a depth of 12 ft. The basins were rectangular in shape, with common wall construction and a length-to-width ratio of 4:1. The maximum individual basin size utilized was 3,800 ft^3 with multiple basins utilized when the total basin volume exceeded 3,800 ft^3. Direct drive centrifugal compressors were used for the air supply, and porous diffusers placed at close intervals over the entire basin bottom were used for air introduction. The air supply system was sized for 5 $scfm/ft^2$ of basin floor area. Although removals are a function of air-to-water ratio, contact time, and water temperature, an air-to-water ratio of 10 ft^3 of air to 1 ft^3 of water should be sufficient for the removal of TTHM. Construction costs are shown in Table 176 and Figure 208.

Table 174

Construction Cost for Below-Ground Clearwell Storage

Cost Category	Clearwell Capacity (gal)					
	10,000	50,000	100,000	500,000	1,000,000	7,500,000
Excavation & Sitework	$ 140	$ 190	$ 410	$ 2,030	$ 19,440	$ 30,020
Concrete	8,250	14,430	23,280	66,330	105,520	622,500
Steel	5,700	9,240	14,550	32,670	113,050	350,700
Labor	13,050	21,480	35,040	84,090	109,290	394,160
Electrical & Instrumentation	1,270	1,270	6,010	6,010	9,800	9,800
SUBTOTAL	28,410	46,610	79,290	191,130	357,100	1,407,180
Miscellaneous & Contingency	4,260	6,990	11,890	28,670	53,570	211,080
TOTAL	32,670	53,600	91,180	219,800	410,670	1,618,260

Table 175

Construction Cost for Ground-Level Clearwell Storage

Cost Category	Clearwell Capacity (gal)						
	8,500	37,600	88,100	475,900	846,000	4,606,200	9,400,400
Manufactured Equipment	$ 6,710	$ 15,580	$ 29,520	$ 78,520	$ 128,920	$ 459,080	$ 797,040
Concrete	5,420	5,580	5,890	8,530	11,130	43,870	84,850
Steel	4,030	4,310	4,580	6,620	8,610	33,950	65,640
Labor	810	850	850	1,230	1,590	6,290	12,150
Pipe and Valves	3,350	4,950	7,390	9,900	13,820	22,280	36,360
Electrical & Instrumentation	1,270	1,270	6,010	6,010	6,010	6,010	6,010
SUBTOTAL	21,590	32,540	54,240	110,810	170,080	581,480	1,002,050
Miscellaneous & Contingency	3,240	4,880	8,140	16,620	25,510	87,220	150,310
TOTAL	24,830	37,420	62,380	127,430	195,590	668,700	1,152,360

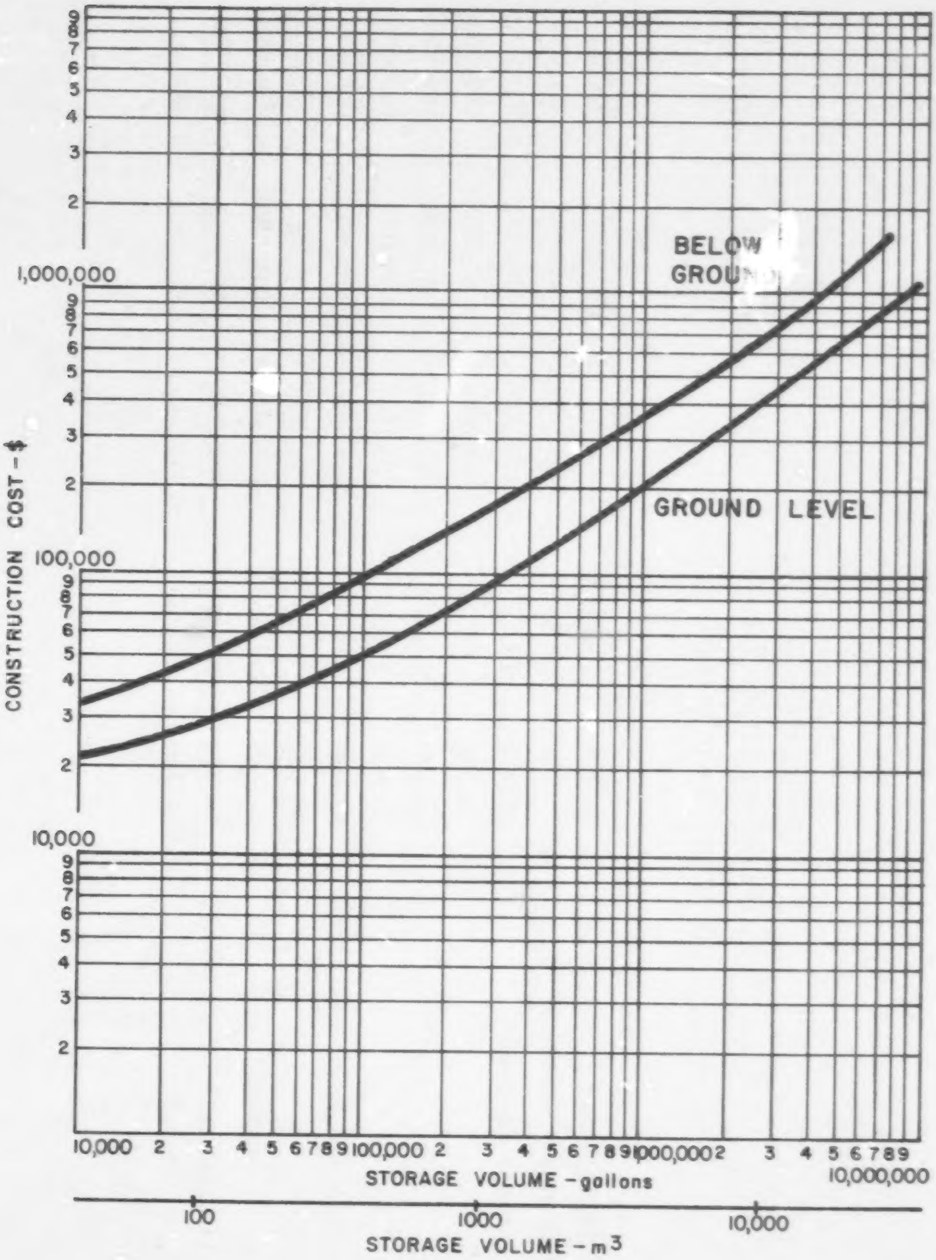


Figure 207. Construction cost for below-ground and ground-level clearwell storage.

Table 176

Construction Cost for Diffused Aeration Basin

Cost Category	Aeration Basin Volume (ft^3) 1,900	19,000	94,000	190,000	380,000
Excavation and Sitework	$ 450	$ 4,700	$ 9,300	$ 19,000	$ 29,000
Manufactured Equipment	48,000	310,000	1,050,000	1,900,000	3,700,000
Concrete	1,380	9,000	29,000	57,000	110,000
Steel	2,100	13,700	44,100	87,000	167,000
Labor	15,500	94,000	295,000	495,000	965,000
Electrical and Instrumentation	14,400	87,000	284,000	475,000	903,000
Housing	14,000	19,200	40,000	48,000	96,000
SUBTOTAL	95,830	537,600	1,751,400	3,081,000	5,970,000
Miscellaneous and Contingency	14,370	80,640	262,710	462,150	895,500
TOTAL	110,200	618,240	2,014,110	3,543,150	6,865,500

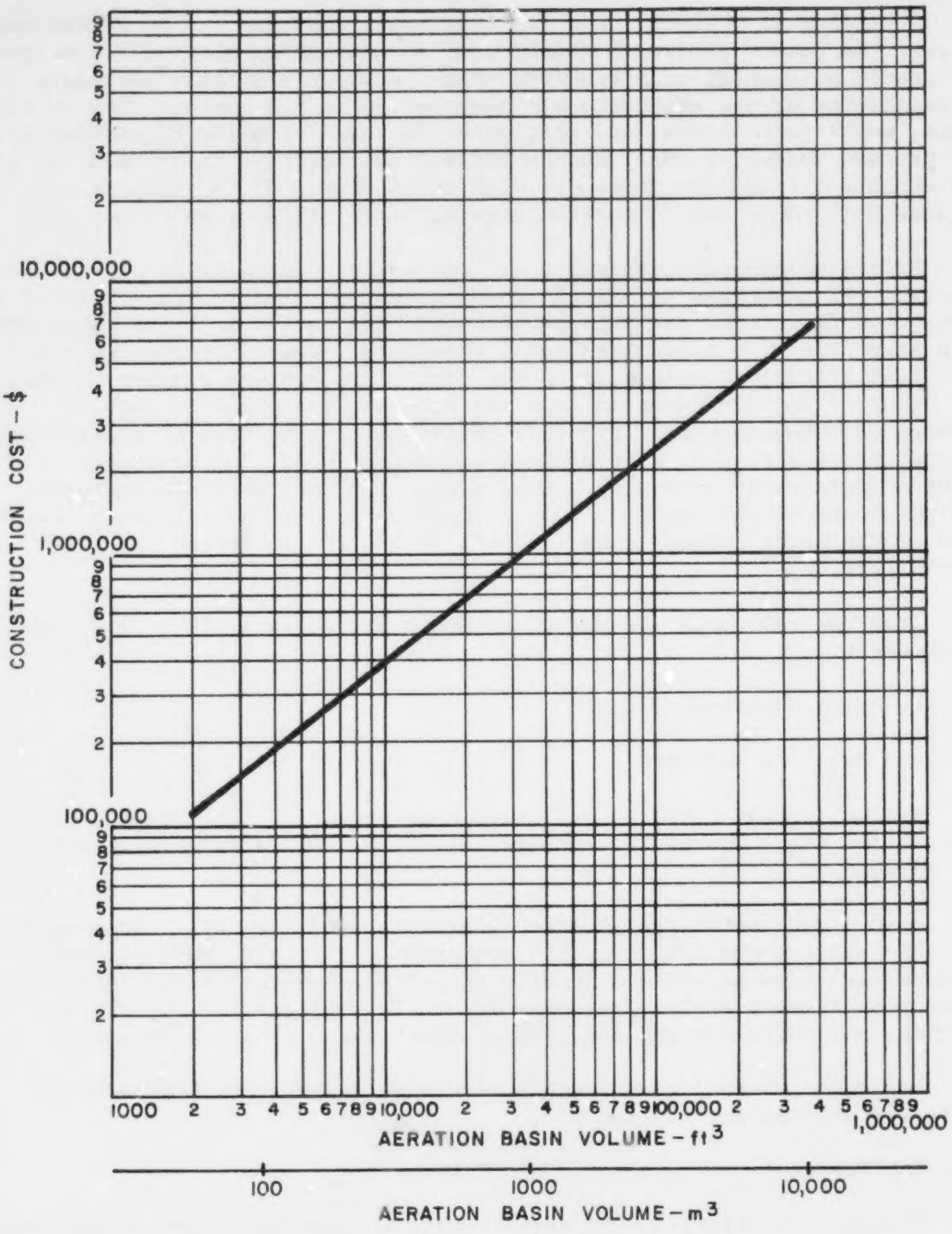


Figure 208. Construction cost for diffused aeration basins.

Aeration Towers--

Stripping of volatile organics from water supplies can be accomplished in aeration towers similar to those used for oxidation of iron and manganese. The degree of removal of a specific organic compound by this technique depends on volatility of the compound, air-to-water ratio and contact time in the tower, water temperature, and many other factors. Limited experience with the process indicates that loading intensities matching those used for iron and manganese oxidation in towers with media depths of 15 to 25 ft will provide between 40 and 90 percent removal of volatile organic compounds.

Estimated construction costs are for rectangular aeration towers with 16-ft of PVC media and an overall tower height of 22-ft. For towers of less than 6,400 ft^3, units are shipped assembled and have reinforced fiberglass skin supported by a galvanized metal framework. Towers of greater volume are field erected from factory-formed components and are similar in design and construction to industrial cooling towers. The exterior skin of corrugated asbestos cement panels is attached to a structural steel framework. Towers are supported by a reinforced concrete basin. The basin collects tower underflow and serves as a pump sump. The cost estimate does not include tower supply pumps or tower underflow pumps. All aeration towers have electrically driven, induced-draft fans with fan stacks and drift eliminators.

Construction costs for aeration towers are shown in Table 177 and Figure 209.

Operation and Maintenance Cost

Diffused Aeration Basins--

Process energy requirements are for operation of the direct drive centrifugal air compressors. Continuous, 24-hr/day, 365-day/year operation was assumed.

Maintenance materials include lubricants, replacement components for air compressors, and air diffusion equipment. Estimates were developed from review of costs associated with activated sludge aeration facilities. Labor requirements include maintenance of air compressors, air piping, valving, and diffusers and for general maintenance of aeration basins.

Estimated operation and maintenance requirements are presented in Table 178 and Figures 210 and 211.

Aeration Towers--

Process electrical energy requirements are for operation of the induced draft fan. A 24-hr/day, 365-day/year operation was assumed. In some instances, pumping energy may also be required, but it is not included because the requirement for it and the rate and head of pumping will vary from application to application. Units are not housed, eliminating the need for building-related energy.

Table 177

Construction Cost
for Aeration Towers

Cost Category	Aeration Tower Volume (ft^3) 680	6,400	32,000	64,000	128,000	256,000
Excavation and Sitework	$ 100	$ 220	$ 900	$1,500	$ 3,000	$ 6,000
Manufactured Equipment	16,000	110,000	192,000	352,000	640,000	1,025,000
Concrete	1,600	10,000	18,000	30,000	57,000	110,000
Steel	2,400	14,000	26,000	43,000	85,000	160,000
Labor	3,100	18,000	42,000	74,000	147,000	289,000
Electrical & Instrumentation	800	3,000	13,000	20,000	30,000	48,000
SUBTOTAL	24,000	155,220	291,900	520,500	962,000	1,638,000
Miscellaneous and Contingency	3,600	23,280	43,790	78,080	144,300	245,700
TOTAL	27,600	178,500	335,690	598,580	1,106,300	1,883,700

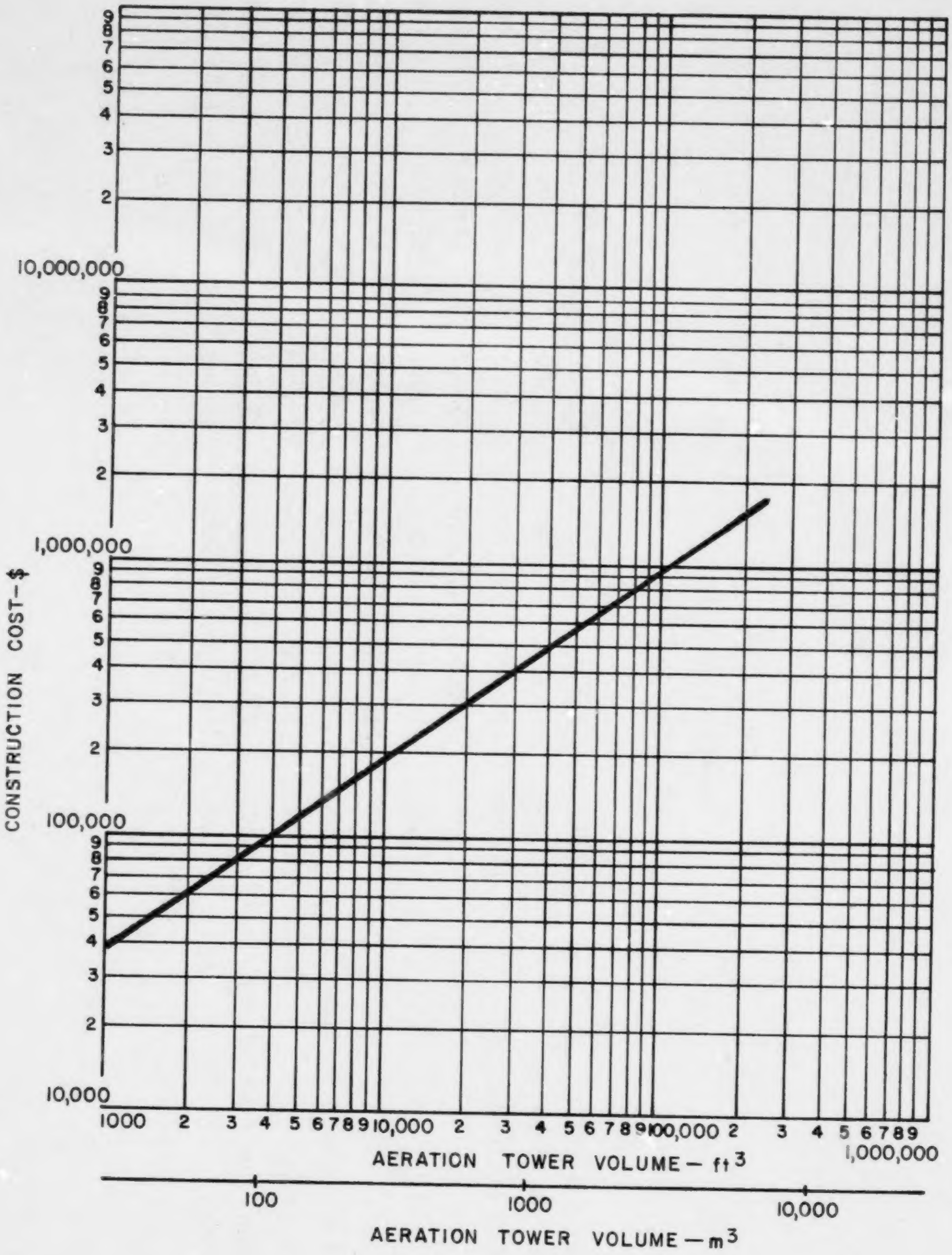


Figure 209. Construction cost for aeration towers.

Table 178

Operation and Maintenance Summary for Diffused Aeration Basins

Aeration Basin Volume (ft^3)	Energy (kw-hr/yr) Building	Energy (kw-hr/yr) Process	Energy (kw-hr/yr) Total	Maintenance Material ($/yr)	Labor (hr/yr)	Total* Cost($/yr)
1,900	16,000	281,400	297,400	$ 3,000	1,500	$ 26,920
19,000	24,000	2,810,000	2,834,000	9,000	4,000	134,020
94,000	50,000	14,285,000	14,335,000	14,000	10,000	544,050
190,000	60,000	28,570,000	28,630,000	18,000	20,000	1,076,900
380,000	120,000	57,140,000	57,260,000	30,000	40,000	2,147,800

*Calculated using $0.03/kw-hr and $10.00/hr for labor.

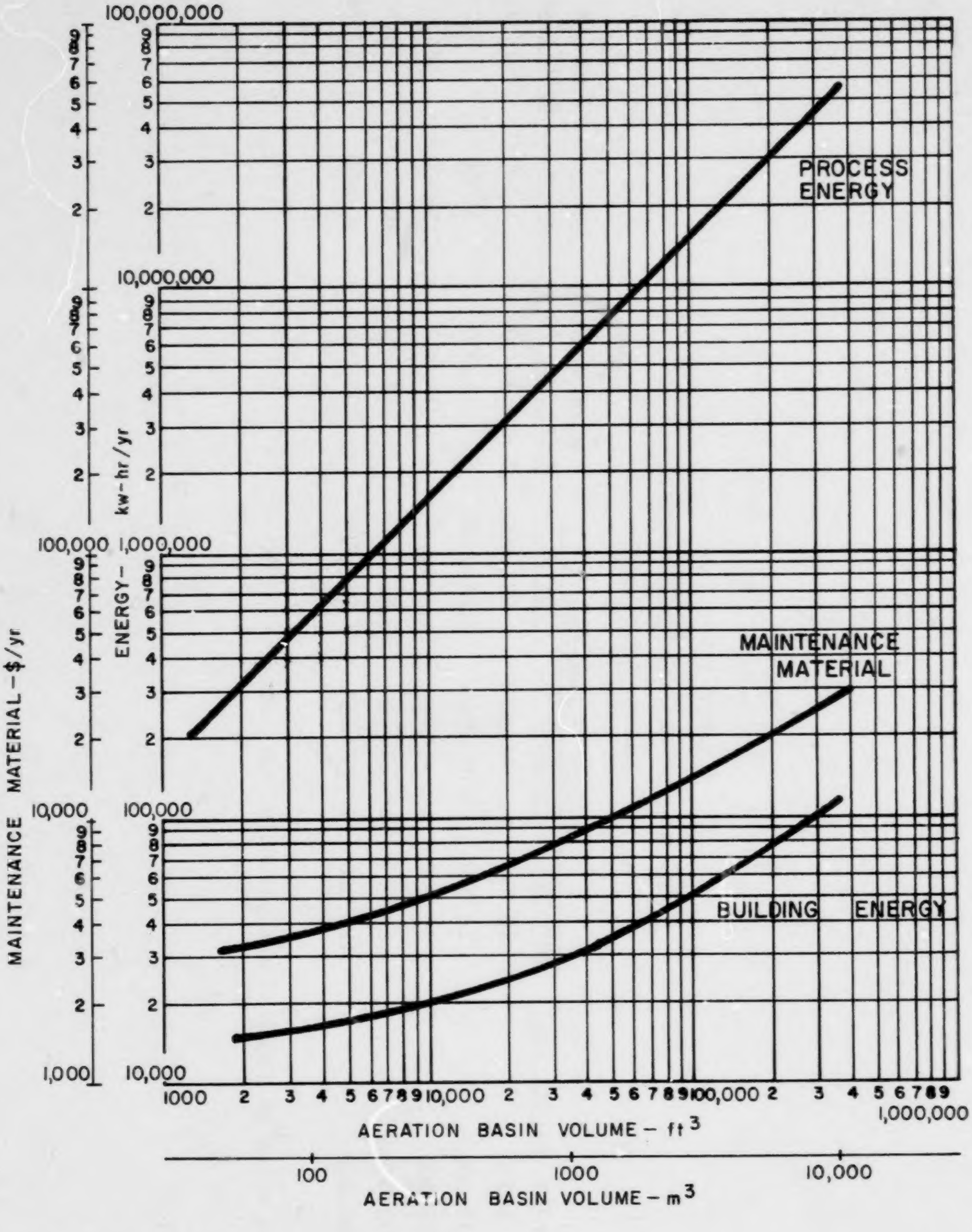


Figure 210. Operation and maintenance requirements for diffused aeration basins - maintenance material, building energy, and process energy.

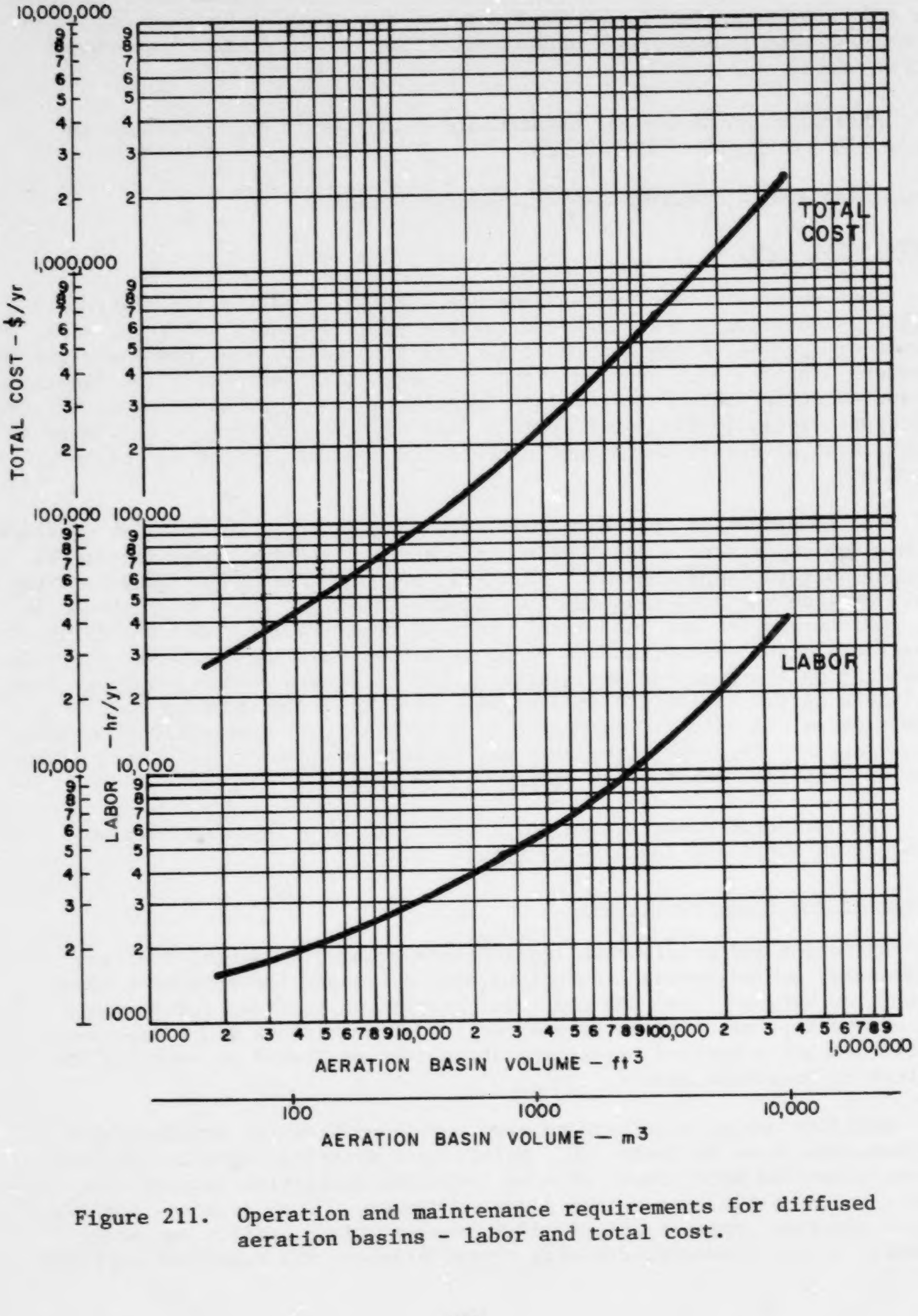


Figure 211. Operation and maintenance requirements for diffused aeration basins - labor and total cost.

Maintenance materials include replacement packing media, lubricants for fans and motors, and other miscellaneous items. Labor requirements include fan and motor maintenance, weekly hosing of distributing nozzles and media to remove slime growths, and occasional repair or replacement of damaged packing media.

Estimated operation and maintenance requirements are presented in Table 179 and Figures 212 and 213.

ADMINISTRATION, LABORATORY AND MAINTENANCE BUILDING

Construction Cost

Most water treatment plants include building area for administrative offices, laboratory, maintenance or shop area, and general storage. The amount of area set aside for these functions varies widely from one plant to another. Factors such as plant capacity, extent of administrative functions conducted at the treatment facility (whether solely for the plant or for other functions also), funding availability, and designer preference will have a significant effect on the amount of building area designated for these functions.

The construction cost curve was developed using building areas obtained from a review of over a dozen water treatment facilities, with capacities ranging between 1 and 100 mgd. It should be noted that these area requirements exclude the area required for chemical storage, which is included in the cost curves for the individual chemical feed systems. In developing the construction cost curve, it was recognized that building costs are variable, depending on the function and design of the facility. Costs can range from as little as \$20 to \$25/ft^2 for storage areas to \$75 to \$80/ft^2 for laboratories. A weighted composite cost of \$45/ft^2 was selected to develop a cost curve. The cost curve does not include laboratory analytical equipment or supplies, maintenance equipment, or vehicles.

The estimated construction costs are shown as a function of plant capacity in Table 180 and also in Figure 214.

Operation and Maintenance Cost

Operation and maintenance requirements related to administrative, laboratory, and maintenance functions were developed for treatment plant capacities between 1 and 200 mgd. Information on staffing requirements and maintenance material costs was obtained from various water treatment facilities and supported by extrapolation from published information for wastewater treatment plants.

Building energy requirements were developed from the building area requirements shown in Table 180. Maintenance material costs are related to operation and maintenance of administrative facilities that are not directly assignable to specific plant components. Such expenses include office supplies, communications, dues, subscriptions, office equipment repairs, travel expenses, training course expense, and custodial supplies.

Table 179

Operation and Maintenance Summary for Aeration Towers

Aeration Tower Volume (ft^3)	Process Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
680	3,270	$ 600	50	$ 1,200
6,400	65,440	1,000	160	4,560
32,000	327,200	3,000	300	15,820
64,000	654,400	6,000	500	30,630
128,000	1,309,000	12,000	900	60,270
256,000	2,618,000	25,000	1,700	120,540

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

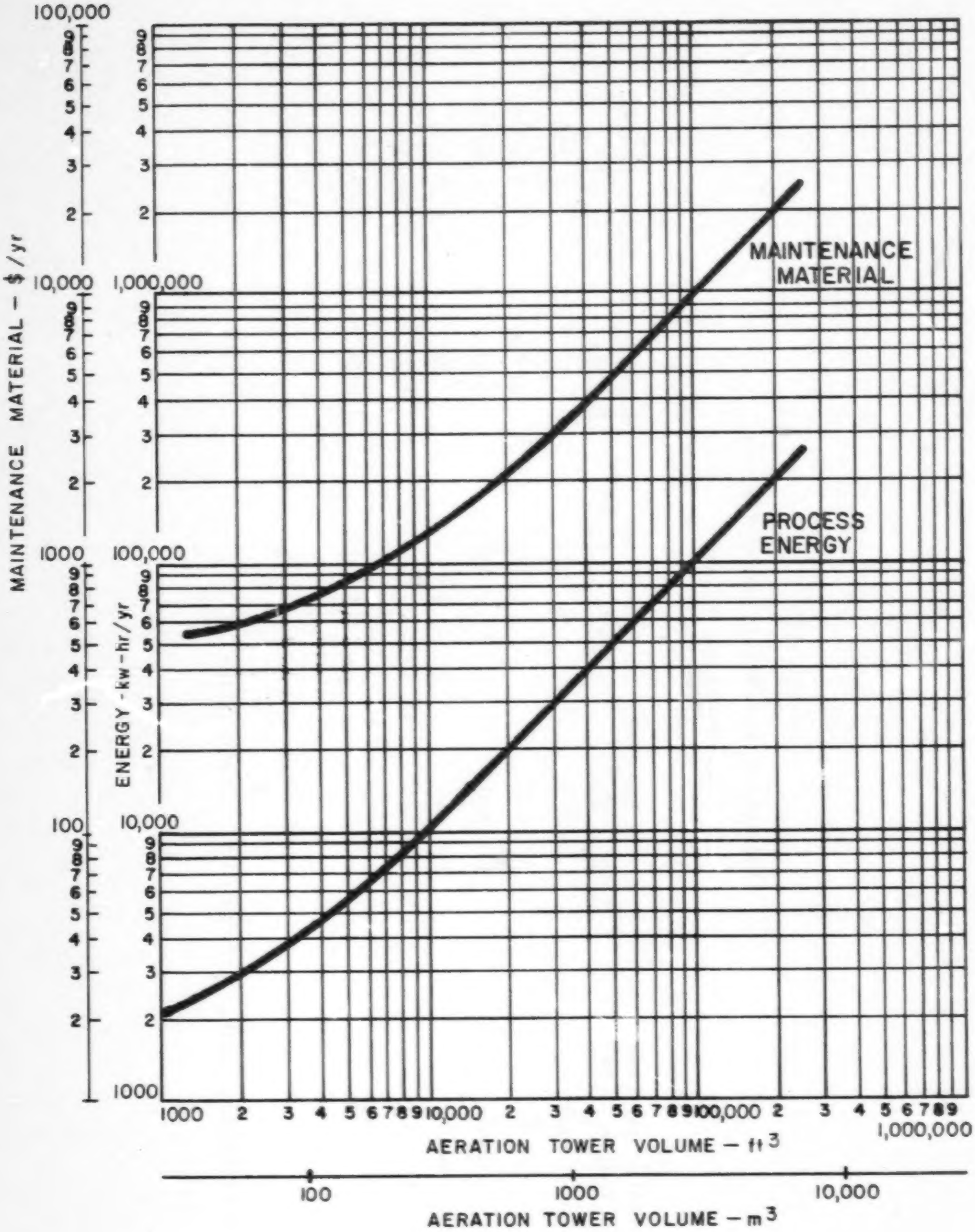


Figure 212. Operation and maintenance requirements for aeration towers - process energy and maintenance material.

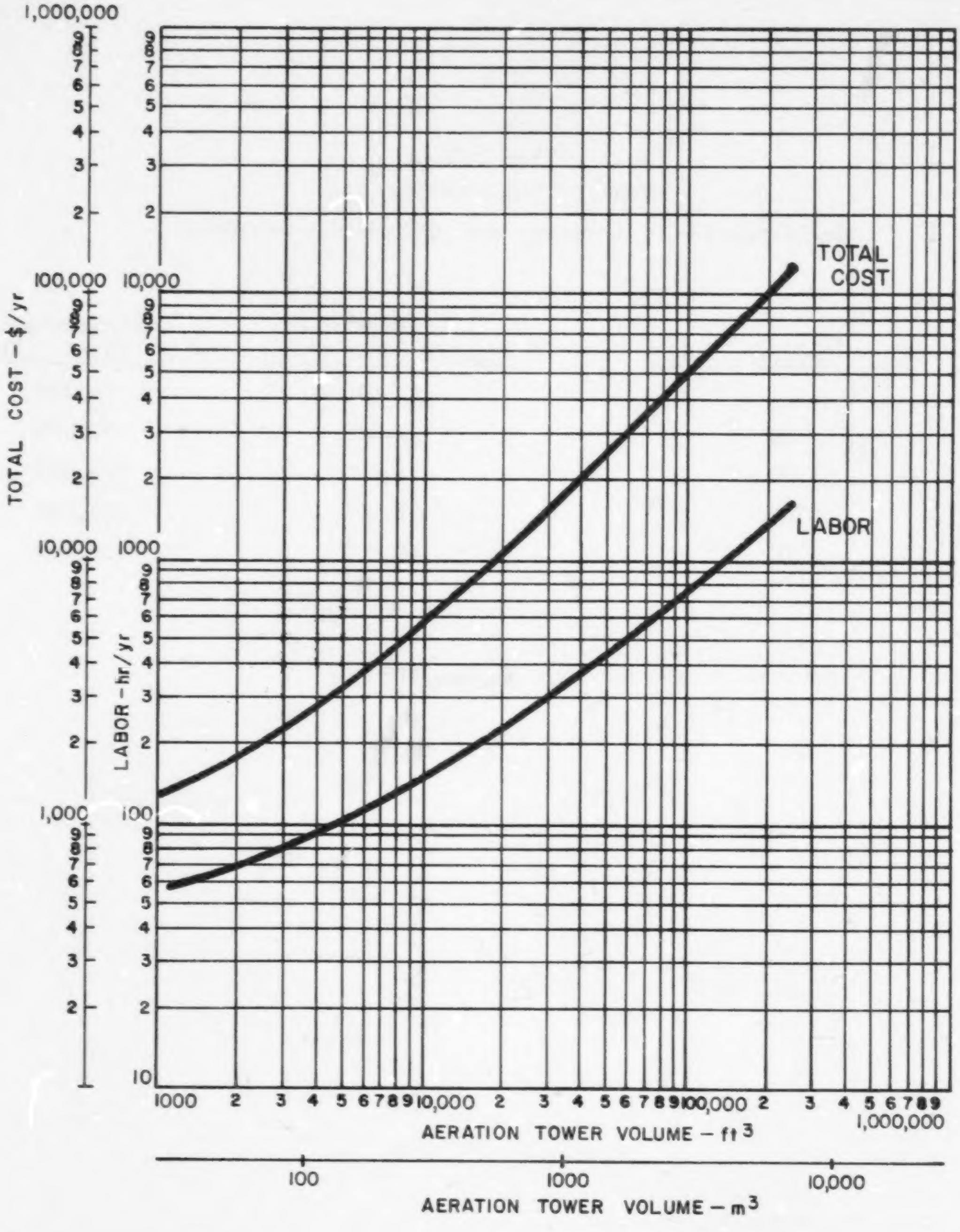


Figure 213. Operation and maintenance requirements for aeration towers - labor and total cost.

Table 180
Construction Cost for Administrative, Laboratory and Maintenance Building

Plant Capacity (mgd)	Building Area Requirements (ft^2)	Construction Cost* ($)
1	550	$ 24,750
10	2,000	90,000
50	6,000	225,000
100	7,200	324,000
200	10,000	450,000

*Based on a weighted composite cost of $45/ ft^2.

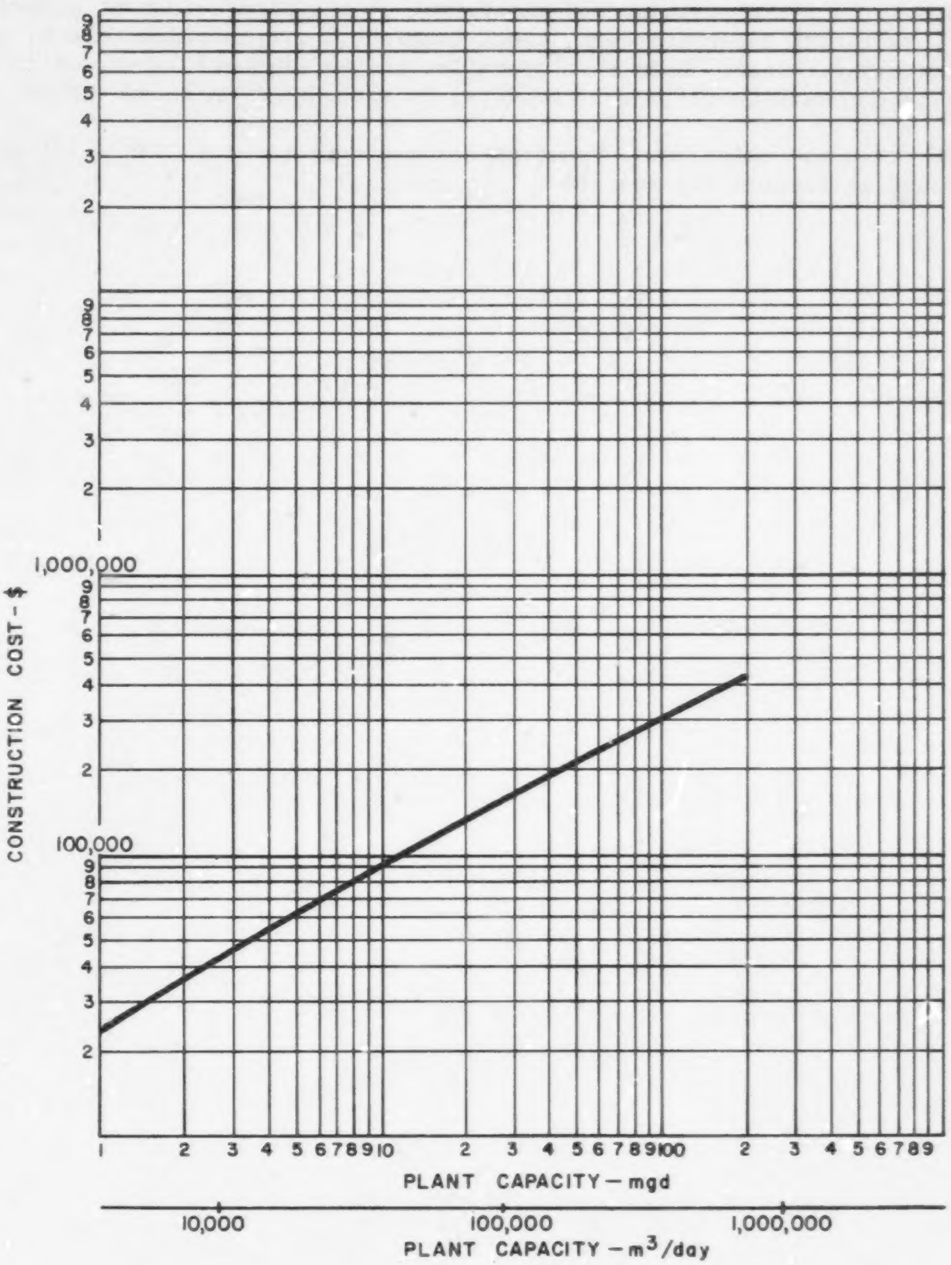


Figure 214. Construction cost for administrative, laboratory, and maintenance building.

Labor requirements are limited to those whose time and effort are related only to administration and management of the plant, such as superintendent, assistant superintendent, plant chemist, bacteriologist, clerk, and maintenance supervisor. Note that operation and maintenance labor, which is included under each specific unit process, is excluded from these curves.

Operation and maintenance requirements are summarized in Table 181 and illustrated in Figures 215 and 216.

Table 181

Operation and Maintenance Summary for Administrative, Laboratory and Maintenance Building

Plant Capacity (mgd)	Building Energy (kw-hr/yr)	Maintenance Material ($/yr)	Labor (hr/yr)	Total Cost* ($/yr)
1	56,400	$ 2,000	1,460	$ 18,290
10	205,000	4,500	6,200	72,650
50	513,000	10,000	10,400	129,390
100	739,000	15,000	12,500	162,170
200	1,030,000	20,000	16,000	210,900

*Calculated using $0.03/kw-hr and $10.00/hr of labor.

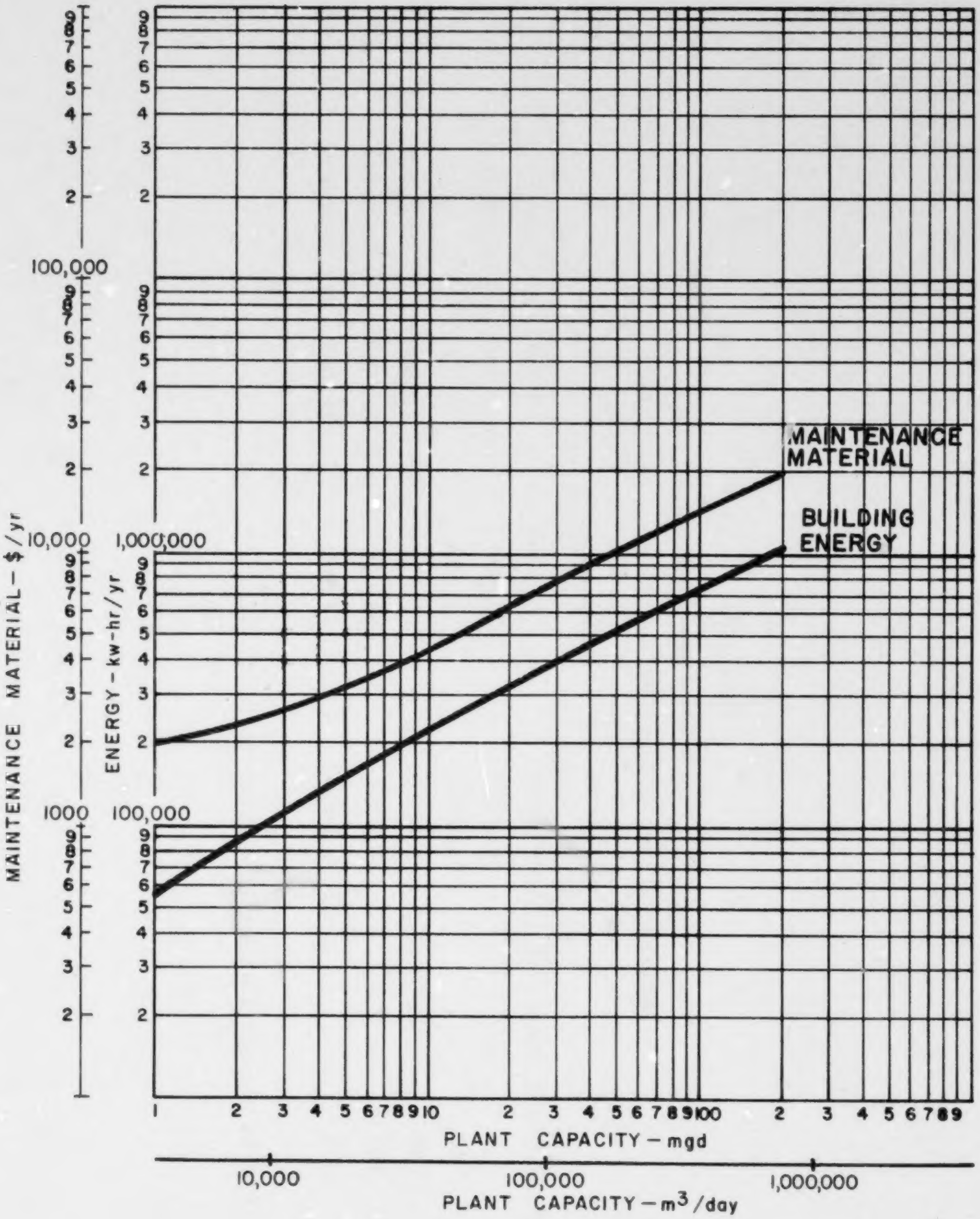


Figure 215. Operation and maintenance requirements for administration, laboratory, and maintenance building - building energy and maintenance material.

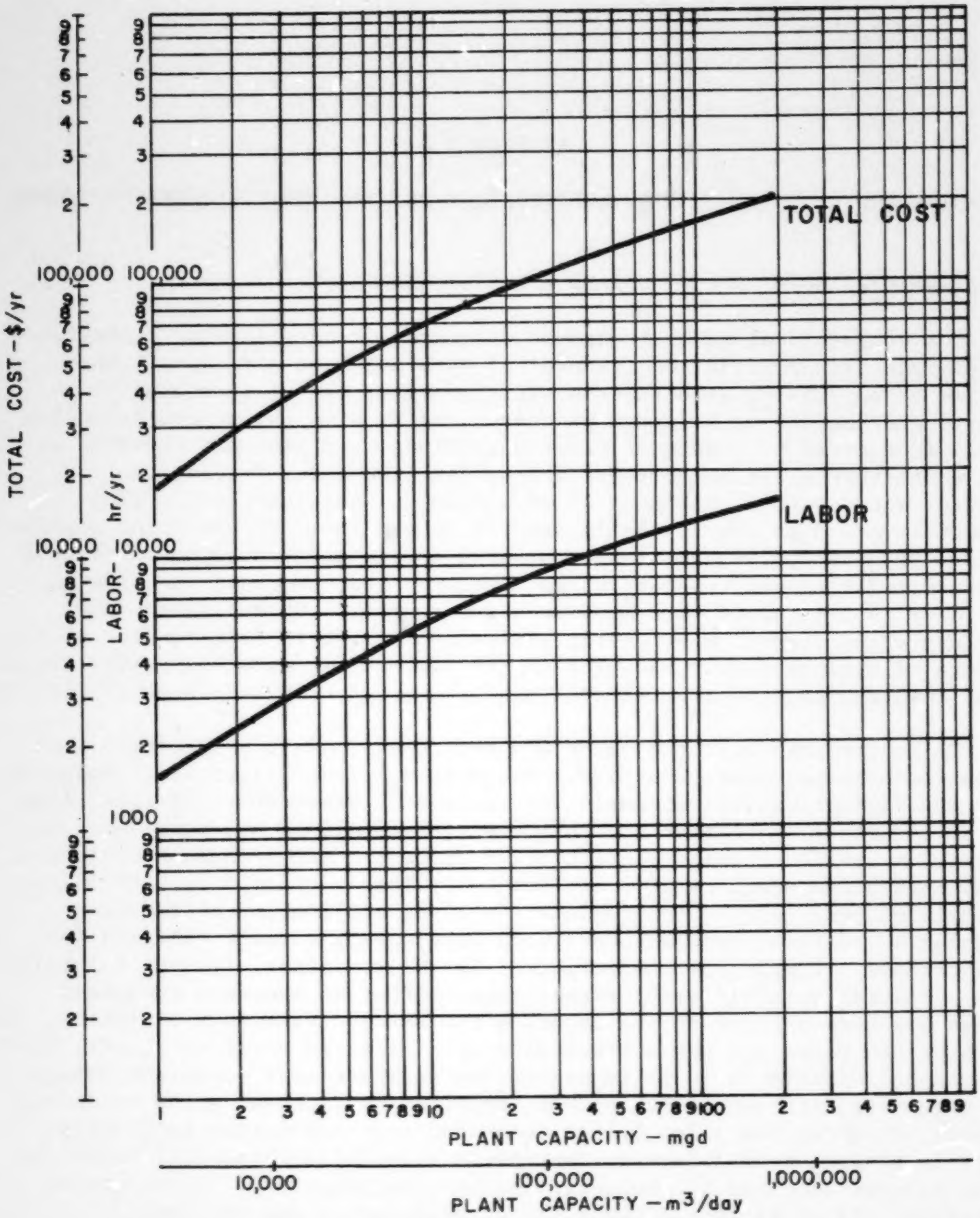


Figure 216. Operation and maintenance requirements for administration, laboratory, and maintenance building - labor and total cost.

SECTION 3

ASBESTOS AND VIRUS REMOVAL BY MODIFICATION OF STANDARD TREATMENT PROCESSES

OPERATING STRATEGIES FOR VIRUS AND ASBESTOS REMOVAL

The conventional water treatment processes of coagulation, filtration, and disinfection provide good removal of both asbestos and virus. When desired or necessary, asbestos and virus removals can be increased by modifying or adding to standard processes and by exercising more extensive and rigid control of treatment plant operations. In general, removals of both constituents can be correlated with filtered water turbidities. Filtered water with a turbidity of less than 0.1 turbidity units (TU) ordinarily would be substantially free of asbestiform fibers of the amphibole group. In addition, Hudson[11] demonstrated a relationship between filtered water turbidities and residual virus particles that suggests that low turbidity is consistent with maximum virus removal. On the other hand, complete virus removal must ultimately be considered to be dependent on the process of disinfection. Coagulation and filtration can provide substantial virus removal, but complete removal can be assured only by proper disinfection.

To insure that filtered water has the lowest possible turbidity, all suspended material must be properly coagulated before filtration. Coagulation and filtration are extremely interdependent processes. In fact, they are so closely related that they can best be visualized and considered as parts of a single coagulation-filtration process. One technique designed to establish the adequacy of coagulation utilizes a pilot filter to filter a sample of coagulated water immediately after application of chemical coagulants. Several manufacturers have developed equipment designed for this purpose. Continuous monitoring of the pilot filter effluent turbidity with a recording turbidimeter establishes whether an adequate coagulant dosage has been applied to the incoming raw water. With this equipment, the operator can preselect the maximum allowable filtered water turbidity, which if exceeded, initiates an alarm signifying an inadequate coagulant dosage. The high turbidity condition is then corrected by increasing the coagulant dosage. By using the pilot filter technique for coagulation monitoring, there is minimal danger that an improperly coagulated water will reach the plant filters and lead to production of an unsatisfactory filtered water turbidity. Pilot filters enhance filter performance and increase assurances that filtered water will be substantially free of asbestos and virus particles. Perhaps of equal importance is the installation and operation of continuous turbidity monitoring equipment on each plant filter effluent line.

ASBESTOS REMOVAL

Considered that the need for asbestos removal has only recently been recognized (about 1973), it is significant that the best methods for treatment are now rather well established. Generally, filter plants should be designed and operated to produce finished water turbidities of 0.1 to 0.2 TU to accomplish virtually complete removal of asbestos-like fibers.

The operating strategy for coagulation, filtration, and disinfection system to remove asbestos involves several factors. Good coagulation is absolutely essential. In this regard, two or three stages of rapid mixing may be required, with several points for application of coagulant chemicals and coagulant aids. Good control of the coagulation process is necessary. This may be accomplished by use of a pilot filter, coagulant control center, or other means. Provision should be made for the introduction of polymer to the flash mixers, the flocculation chambers, the filter beds, or any combination of the three locations. In some cases, the use of two different polymers may be helpful. Amphibole fiber removal accomplished by tri-media filters exceeds that accomplished by the dual-medial filters. Therefore, a positive-head, tri-media filter designed to operate at a rate of 290 m^3/m^2 per day (5 gpm/ft^2) at design flow is recommended. Although sedimentation is not required for fiber removal, presedimentation could be used to reduce the solids loading to the filters and to extend filter run lengths. In some instances, direct filtration may be practical. Quality control of filter operations should be based on maintaining a finished water having a turbidity of not greater than 0.1 TU.

In-line turbidimeters should be used for continuous monitoring of the raw and finished water turbidity, as well as that of the effluent from the pilot filter and each individual plant filter unit. Analyses for asbestiform fiber counts should be performed regularly on raw and finished water samples to check on the efficiency of fiber removal. Provisions must be made to insure that asbestos fibers in settling basin sludge and settled filter backwash water do not reach the original water sources. A wash water recovery system is advisable. Sludges may go to a lagoon or sanitary landfill.

The potential modifications required at most existing filter plants to enhance asbestos removal include:

1. Addition of one or two stages of rapid mixing;

2. Provision for feeding polymers or other coagulants or coagulant aids not used in normal treatment;

3. Addition of a pilot filter, a coagulant control center, and automated sampling devices;

4. Provision for mixed-media filters rather than dual or single-media filters;

5. Installation of turbidity monitoring equipment on each filter effluent line and on the clearwell or combined finished water discharge line;

6. Provision for higher-than-normal filter backwash rates;

7. Addition of a wash water recovery system.

8. Provision for safe (usually lagoon or landfill) disposal of settling basin and backwash sludge containing asbestos; and

9. Acquisition of laboratory equipment to measure asbestos fiber removal.

Experts in water treatment will recognize that many, if not all, of these features have been incorporated into many new water purification plants built since about 1960. Also, many older plants have recently added these features to improve finished water quality, control of plant operations, and the reliability of treatment processes.

Added Costs For Asbestos Removal In New Plants.

If the best in coagulation, filtration, and disinfection are needed in a new plant for purposes other than asbestos removal, then the only additional construction costs to be allocated totally to asbestos removal would be for the above items 1, 2, 6, 8, and 9. The cost of items 3, 4, 5, and 7 could be prorated between asbestos removal and the other purposes served by these features. The total construction cost attributable to asbestos removal could then be estimated by use of the cost curves contained in this report for:

1. Rapid mix
2. Polymer feed systems
3. Alum feed systems
4. Backwash pumping facilities
5. Sludge dewatering lagoons
6. Total microscopic particle counter

The the total construction cost of the appropriate items from the above list must be added to the costs for the contractor's overhead and profit, land, interest during construction, engineering, and legal, fiscal, and administrative services. Costs for operation and maintenance of the above items can be estimated from the operation and maintenance cost curves included in this report. Examples are contained in Volume 1 to show the method of determining capital cost, operation and maintenance cost, and total cost.

Added Costs For Asbestos Removal In Existing Plants

If an existing plant is to be modified for the purpose of removing asbestos, then the total cost of all new facilities would be allocated to asbestos removal. In addition to the items shown on the above list, other modifications or additions that may be required are:

1. Modification of rapid sand filters to high-rate filters
2. Wash water surge basin
3. Coagulation control with pilot filters
4. Automatic chemical dosage control with pilot filters
5. Addition of in-line turbidimeter

Construction and operation and maintenance curves for these facilities or modifications are included within this report. Items 1 and 2 are included with the cost curves for 1 to 200-mgd treatment facilities, and items 3, 4, and 5 are included within this section.

One additional possibility is that a need may arise for more highly skilled operators. Such an additional cost would also have to be charged to asbestos removal.

VIRUS REMOVAL

As mentioned previously, complete virus removal can be obtained only by adequate disinfection. Suitable drinking water disinfectants for use in virus inactivation include free chlorine, ozone, and chlorine dioxide. In cases where trihalomethane production is a problem, chlorine-ammonia may also be considered if properly used.

Excess turbidity can encapsulate virus and prevent contact with the disinfectant applied to the water. Organic matter, iron, manganese, color bodies, and other substances can react with some disinfectants and reduce the total amount of the disinfectant remaining to inactivate the virus. Removal of turbidity and other foreign substances by coagulation, settling, and filtration thus greatly facilitates proper disinfection by optimizing conditions under which disinfection takes place. It is generally agreed that turbidities should be reduced to less than 1.0 TU before final disinfection. There is some support for the idea that further reduction of turbidity to the 0.1 to 0.2 TU range provides even better conditions for disinfection, but this view is not universal.

One operating strategy for virus inactivation is as follows:

1. The turbidity of the water should be < 1.0 TU, and preferably <0.1 TU.

2. The pH of the water should be close to 7.5 for waters containing ammonia, or <7.0 for ammonia-free waters.

3. Rapid, uniform mixing of water and chlorine must be provided.

4. A concentration of 0.5 to 1.0 mg/l of undissociated hypochlorous acid (HOCl) must be maintained in the water being treated for a contact period of 30 min.

Ozone has a greater germicidal effectiveness against virus than does chlorine, and its potency is not affected by pH or ammonia content. With proper mixing and the recommended dosage of not <1 mg/l ozone, a contact time of 5 min is adequate in clear water (<1 TU).

In many older, existing filter plants there are several potential changes that could be made to improve virus removal, including:

1. Provision for feeding polymers not used in normal treatment to rapid mix or flocculation basins and to filter beds.
2. Provision for mixed-media or dual-media rather than single-media filters.
3. Installation of turbidity monitoring equipment immediately ahead of the point of chlorine addition as well as on each filter effluent.
4. Addition of pilot filter, coagulant control center, and automated sampling devices.

B. Disinfection (with chlorine)

5. Improved mixing at point of chlorine addition.
6. Installation of continuous-recording chlorine residual analyzer.

In most new plants, most of all of these items would be provided, and the costs to be allocated to virus removal could be prorated based on all benefits realized from installation and use of such facilities.

In existing plants, if the sole or main purpose of the improvements is to increase viral inactivation, then the total cost of improvements should be charged to virus removal.

The cost estimates in this report that can be used to determine the construction and operation and maintenance costs for virus removal are:

1. Breakpoint Chlorination - Chlorine storage and feed systems
2. Ozone generation systems and contact chambers.
3. Chlorine dioxide generating and feed systems.
4. Polymer feed systems.
5. Coagulation control with pilot filters.
6. Modification of rapid sand filters to high-rate filters.
7. Automatic chemical dosage control with pilot filters.

Cost curves for items 1, 2, 3, 4 and 6 are included with the cost curves for 1 to 200-mgd treatment facilities, and items 5 and 7 are included in this section. After the necessary individual construction cost items are selected for a project and totaled, applicable allowances must be added for contractor's overhead and profit, engineering, interest during construction, and legal, fiscal, and administrative costs. Costs for operation and maintenance can be estimated from the cost curves for the same items plus the costs for chemicals. Examples are provided in Volume 1 of this report to illustrate the method for adding these costs to obtain the total cost of treatment.

COST ESTIMATES FOR UNIT PROCESSES TO REMOVE ASBESTOS AND VIRUS

Filtered Water Quality Monitoring With Total Particle Counters

Continuous filter effluent quality monitoring is a prerequisite to achieving maximum assurance of removal of asbestiform particles and virus. Turbidity measurement, which is a widely used technique, provides an indirect indication of the effectiveness of the filtration process in removing these contaminants. A total particle counter, however, provides a direct measurement of the particulate material present in water and is not influenced by particle size, shape, refractive index, and other parameters as are turbidity measurements. For these reasons, the total particle counter offers promise of being a very useful and sensitive process control tool in water treatment practice, and especially where there is proven presence of asbestiform fibers in drinking water supplies.

Although there are several techniques for measuring and counting particles in water, the only instrument currently available that lends itself to continuous monitoring and flexible operation (batch or continuous sampling) is the HIAC Particle Size Analyzer. This instrument operates on the principal of light blockage, in which particles passing by a window or accurately established area are measured and counted individually according to their maximum projected area or equivalent spherical diameter. Particles ranging in size from 1 to 9,000 μm can be measured; however, the most common size range for use in water treatment is 2.5 to 150 μm.

The total particle counter can be used either as a laboratory unit or installed on filter effluent piping to provide continuous monitoring of filtered water quality. The number of units employed in a treatment facility could vary, depending on numerous factors.

A single unit would suffice as a laboratory tool to analyze filtered effluent samples periodically for correlation to turbidity results and for general monitoring at other process points. A more elaborate installation would involve placement of particle counter sensors at each filter effluent, much as is currently done with turbidimeters.

Construction costs for total particle counting systems are presented in Table 182. Costs are presented for a laboratory unit with 12 particle-size-range sensors useful as a research tool and for a continuous filter effluent

Table 182

Construction Cost for Total Particle Counter Systems

	Equipment Description	
Cost Category	Laboratory Unit	Filter Effluent Monitor (per filter)
Equipment	$ 15,000	$ 6,000
Pipe and Valves	--	350
Installation Labor	--	250
Electrical Equipment	--	200
TOTAL COST	$ 15,000	$ 6,800

monitoring system that includes a unit with only three sensors covering the size range typical of particles in filtered waters. The latter system includes sample pumps and electrical interconnection between sensor and readout device.

Coagulation Control with Pilot Filters

To insure that filtered water has the lowest possible turbidity, all suspended material must be properly coagulated before filtration. One technique designed to establish the adequacy of coagulation utilizes a pilot filter to filter a sample of coagulated water immediately after application of chemical coagulants. Several manufacturers have developed equipment designed for this purpose. Continuous monitoring of the pilot filter effluent turbidity with a recording turbidimeter establishes whether an adequate coagulant dosage has been applied to the incoming raw water. With this equipment, the operator can preselect the maximum allowable filtered water turbidity, which, if exceeded, initiates an alarm signifying an inadequate coagulant dosage. The high turbidity is then corrected by increasing the coagulant dosage. With the pilot filter technique for coagulation monitoring, there is minimal danger that an improperly coagulated water will reach the plant filters and lead to production of an unsatisfactory filtered-water turbidity. Pilot filters enhance filter performance and increase assurances that filtered water will be substantially free of asbestos and virus particles. Figure 217 is a schematic flow diagram showing the location of a pilot filter used to monitor coagulation.

Two models are available from suppliers. One model contains a single pilot filter in which the sample flow to the turbidimeter is interrupted each time the pilot filter is backwashed. A second model utilizes two pilot filters, allowing continuous monitoring, even with one filter being backwashed. The single filter unit is generally reserved for small plants (less than 5 mgd).

Construction costs for coagulation control provisions are presented in Table 183. As can be seen, the cost of this equipment is not related to treatment plant capacity. Costs include the pilot filter module, rapid mix sample pump, and chemical feed package.

Automatic Chemical Dosage Control With Pilot Filters

At least one manufacturer offers a pilot filter accessory that automatically adjusts coagulant dosage to match raw water coagulant demands. This automatic dosage control makes possible continuous feeding of coagulant at the precise dosage necessary to maintain a preset filtered water clarity. Turbidity readings from the pilot filter turbidimeters are fed into a black box, which in turn controls the output of chemical feed pumps. The operator establishes this clarity by either increasing or decreasing the chemical dosage, depending on whether the pilot filter turbidity is below or above the set point value. Changes in plant flow rate are also compensated for in the controller.

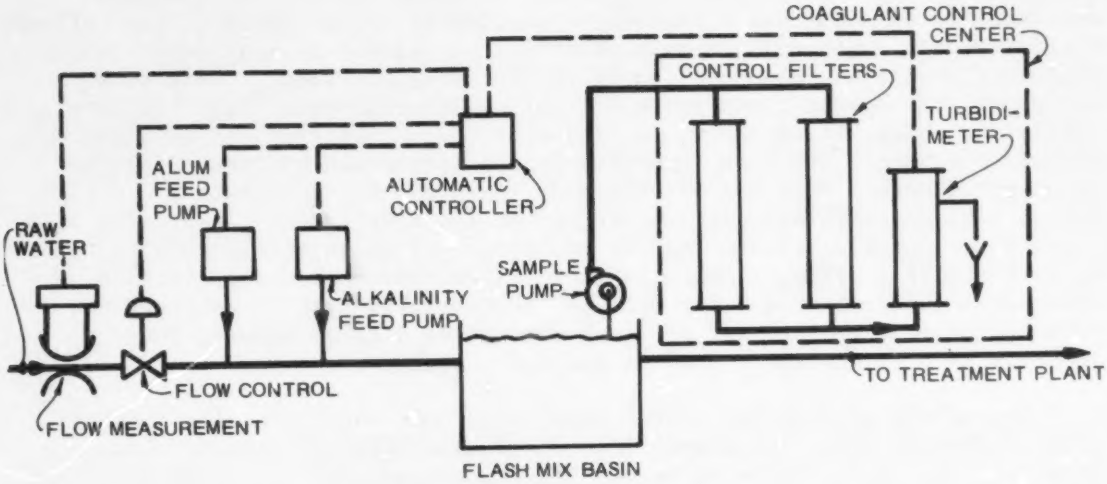

COAGULANT CONTROL CENTER
CONTROL FILTERS
TURBIDIMETER
AUTOMATIC CONTROLLER
ALUM FEED PUMP
RAW WATER
SAMPLE PUMP
ALKALINITY FEED PUMP
FLOW CONTROL
FLOW MEASUREMENT
TO TREATMENT PLANT
FLASH MIX BASIN

Figure 217. Flow diagram for automatic coagulant dosage control.

Table 183

Construction Cost for Coagulation Control with Pilot Filters

Cost Category	Equipment Description		
	Single-Pilot Filter	Dual-Pilot Filter	Automatic Chemical Dosage Control Accessory and Dual-Pilot Filter
Manufactured Equipment	$24,000	$32,900	$38,400
Pumps, Piping & Valves	350	400	400
Installation Labor	1,000	1,500	1,500
SUBTOTAL	25,350	34,800	40,300
Electrical Equipment	3,800	5,220	6,050
TOTAL COST	29,150	40,020	46,350

This type of control device eliminates possible over or under feed of coagulant, which can lead to high filtered-water turbidities. With this equipment, there is increased assurance that the plant filters will continually produce a high clarity (turbidity <0.1 TU), filtered water supply containing the lowest possible level of asbestos or virus particles.

A schematic flow diagram that shows the location of the automatic chemical dosage control is shown in Figure 217. Costs for this accessory are presented in Table 183. Note that the control device needs a continuous turbidity input signal so it can only be used with a dual pilot filter. The unit is mounted in the coagulation control center cabinetry and output signals are extended to plant chemical feed pumps.

Filter Effluent Turbidimeters

Continuous monitoring of filtered water turbidity with accurate, low-cost turbidimeters is an indirect but applicable method of determining the effectivenss of asbestiform fiber and virus removal by the filtration process. Generally speaking, the measurement of turbidity may be used to indicate the probable escape of virus or asbestiform particles into the drinking water supply.

For the measurement of extremely small amounts of turbidity, the principle of light scattering (nephelometry) is used. In the turbidimeter, an intense light is reflected at right angles to the light beam by particles in the water. The amount of reflected light is directly dependent on the concentration of particles in the water. The reflected light is sensed by a photocell, which transmits a signal proportional to the amount of turbidity to a meter calibrated in turbidity units.

Construction costs were developed for a turbidimeter assembly suitable for continuous monitoring of turbidity from individual filters, a well supply, water distribution system, or from other sources. Included is a nephelometry-style turbidimeter with mounting panel, air removal tube, locally mounted master indicator, and power supply. For remote readout, an indicator, shielded cable, and an output signal transmitter are necessary and are included in the cost estimates. In gravity filtration plants, the sensing unit and power supply are generally mounted in the filter gallery. A sample pump is generally necessary to provide a uniform flow of water to turbidimeters located in the gravity filter pipe gallery, and it is included in the costs. The costs also include sample piping and valving between the turbidimeter and the plant filter, and electrical interconnection between the turbidimeter and remove readout instrumentation. The construction cost estimate is shown in Table 184.

Table 184

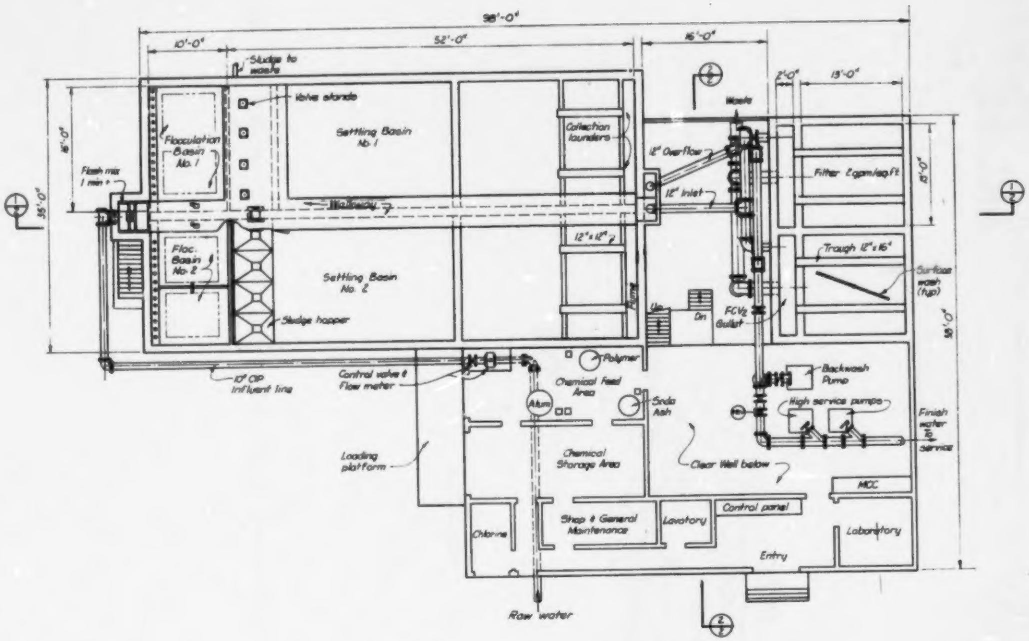
Construction Cost for Filter Effluent Turbidimeters

Cost Category	Cost
Manufactured Equipment	$ 1,300
Labor	200
Pumps, Pipe and Valves	350
Electrical & Instrumentation	200
SUBTOTAL	2,050
Miscellaneous & Contingency	210
TOTAL	2,260

SECTION 4

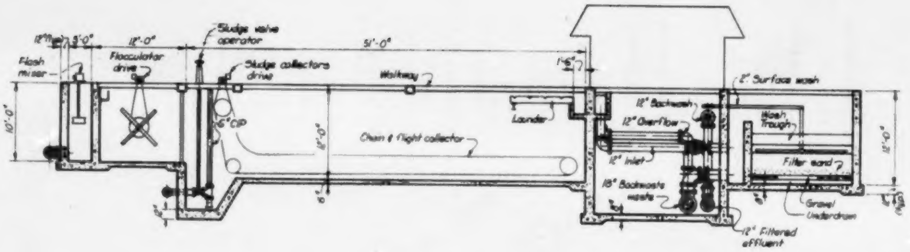
FACILITY LAYOUTS FOR TYPICAL 1, 10, AND 100 MGD PLANTS

Figures 218 through 227 contain facility layouts and cross-sections for typical 1, 10, and 100-mgd water treatment plants. These layouts are included to illustrate typical layouts and space requirements for treatment plants. The drawings are not intended to be utilized for detailed design purposes, but rather to acquaint those unfamiliar with water treatment plants with the basic plant configurations.

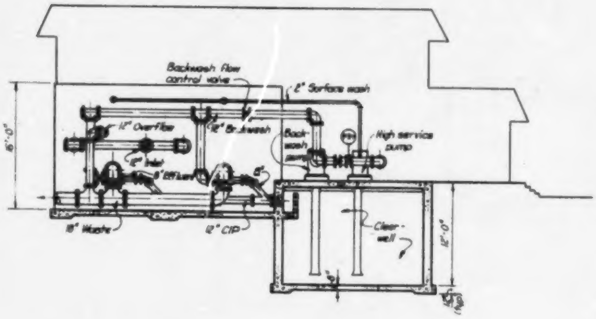

98'-0"
10'-0"
52'-0"
16'-0"
2'-0"
13'-0"
16'-0"
35'-0"
13'-0"
50'-0"
Sludge to waste
Valve stands
Flash mix 1 min +
Flocculation Basin No. 1
Floc. Basin No. 2
Settling Basin No. 1
Settling Basin No. 2
Walkway
Sludge hopper
10" CIP Influent line
Control valve & Flow meter
Loading platform
Collection launders
12"x12"
12" Overflow
12" Inlet
Waste
Filter 2gpm/sq.ft
Trough 12"x16"
Surface wash (typ)
Up
Dn
FCV2 Outlet
Polymer
Chemical Feed Area
Alum
Soda Ash
Chemical Storage Area
Backwash Pump
High service pumps
Finish water To service
Clear Well below
MCC
Control panel
Chlorine
Shop & General Maintenance
Lavatory
Laboratory
Entry
Raw water

DESIGN CRITERIA	
PLANT FLOW:	1
FLASH MIX BASINS:	
Number	1
Detention	1 min.
Volume	700 gal
Mixer:	
Number	1
Hp	1
Velocity gradient	700 sec^{-1}
FLOCCULATION BASINS:	
Number	2
Detention	30 min
Volume	21,000 gal
Flocculators:	
Number	2
Type	Horizontal paddle
Hp	½
Velocity gradient	50 sec^{-1} max (variable)
SEDIMENTATION BASINS:	
Number	2
Overflow rate	600 gpd/ft^2
Volume	62,500 gal each
Weir length	32 ft/basin
Type Collector	Chain & flight
FILTERS:	
Number	2
Type	Rapid sand
Filter rate	2 gpm/ft^2
Backwash rate:	
Nominal	15 gpm/ft^2
Maximum	18 gpm/ft^2

Figure 218. Facility layout for 1-mgd treatment plant.

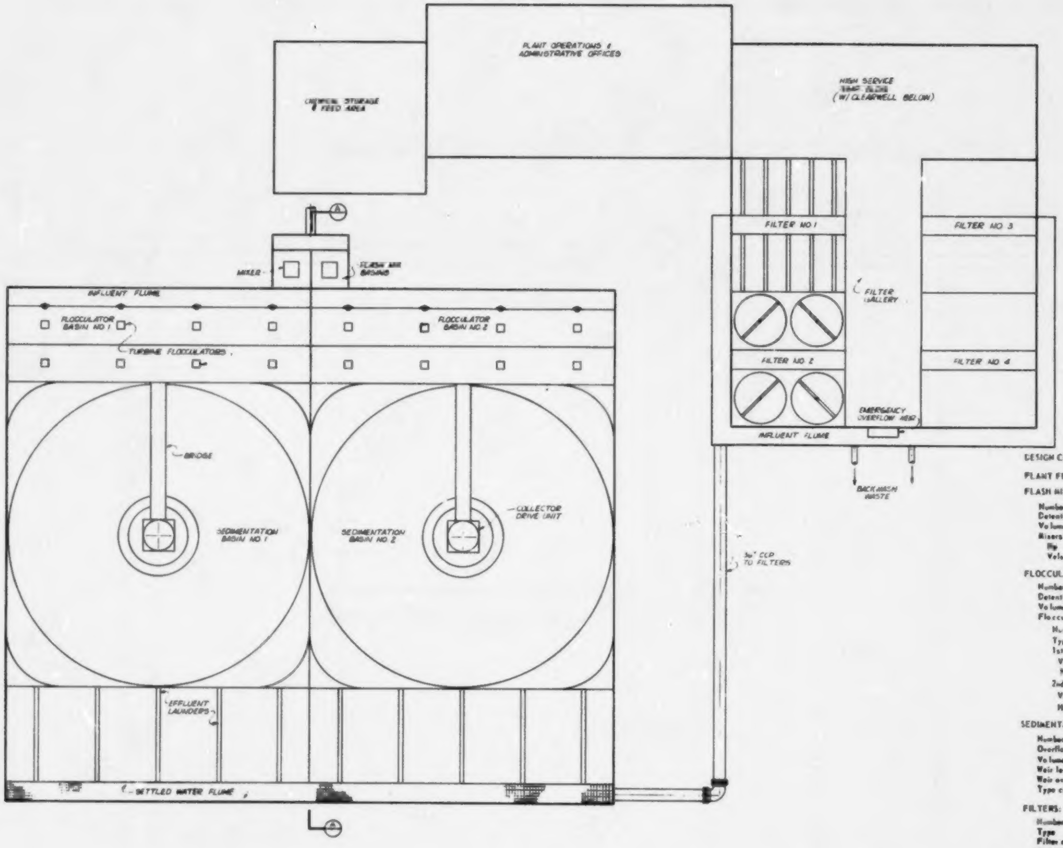

12" Wall
3'-0"
12'-0"
Sludge valve operator
51'-0"
Flash mixer
Flocculator drive
Sludge collectors drive
Walkway
1'-6"
2" Surface wash
10'-0"
6" CIP
12'-0"
Chain & flight collector
Launder
12" Backwash
12" Overflow
Wash trough
12'-0"
12" Inlet
Filter sand
18" Backwaste waste
Gravel
Underdrain
12" Filtered effluent

SECTION 1


Backwash flow control valve
2" Surface wash
16'-0"
12" Overflow
12" Backwash
Back-wash pump
High service pump
12" Inlet
8" Effluent
8"
18" Waste
12" CIP
Clear-well
12'-0"

SECTION 2

Figure 219. Sectional views of 1-mgd water treatment plant.


CHEMICAL STORAGE & FEED AREA
PLANT OPERATIONS & ADMINISTRATIVE OFFICES
HIGH SERVICE PUMP BLDG (W/ CLEARWELL BELOW)
FILTER NO 1
FILTER NO 2
FILTER NO 3
FILTER NO 4
FILTER GALLERY
EMERGENCY OVERFLOW WEIR
INFLUENT FLUME
BACKWASH WASTE
36" CCP TO FILTERS
A
MIXER
FLASH MIX BASINS
INFLUENT FLUME
FLOCCULATOR BASIN NO 1
FLOCCULATOR BASIN NO 2
TURBINE FLOCCULATORS
BRIDGE
SEDIMENTATION BASIN NO 1
SEDIMENTATION BASIN NO 2
COLLECTOR DRIVE UNIT
EFFLUENT LAUNDERS
SETTLED WATER FLUME
A

DESIGN CRITERIA

PLANT FLOW:	10
FLASH MIX BASINS:	
Number	2
Detention	1 min
Volume	3500 gal
Mixers:	2
Hp	5
Velocity gradient	700 sec^{-1}
FLOCCULATION BASINS:	
Number	2 (two compartment)
Detention	30 min
Volume	210,000 gal
Flocculators:	10'
Number	16
Type	Vertical turbine
1st stage:	
Velocity gradient	75 sec^{-1}
Hp	¼
2nd stage:	
Velocity gradient	25 sec^{-1}
Hp	½
SEDIMENTATION BASINS:	
Number	2
Overflow rate	600 gpd/ft^2
Volume	800,000 gal each
Weir length	250 ft/basin
Weir overflow rate	20,000 gpd/lin ft
Type collector	Circular w/corner sweeps
FILTERS:	
Number	4 (2 cell)
Type	Rapid sand
Filter rate	2 gpm/ft^2
Back wash rate:	
Nominal	15 gpm/ft^2
Maximum	18 gpm/ft^2

Figure 220. Facility layout for 10-mgd water treatment plant.

Reproduced from best available copy.

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best available copy.

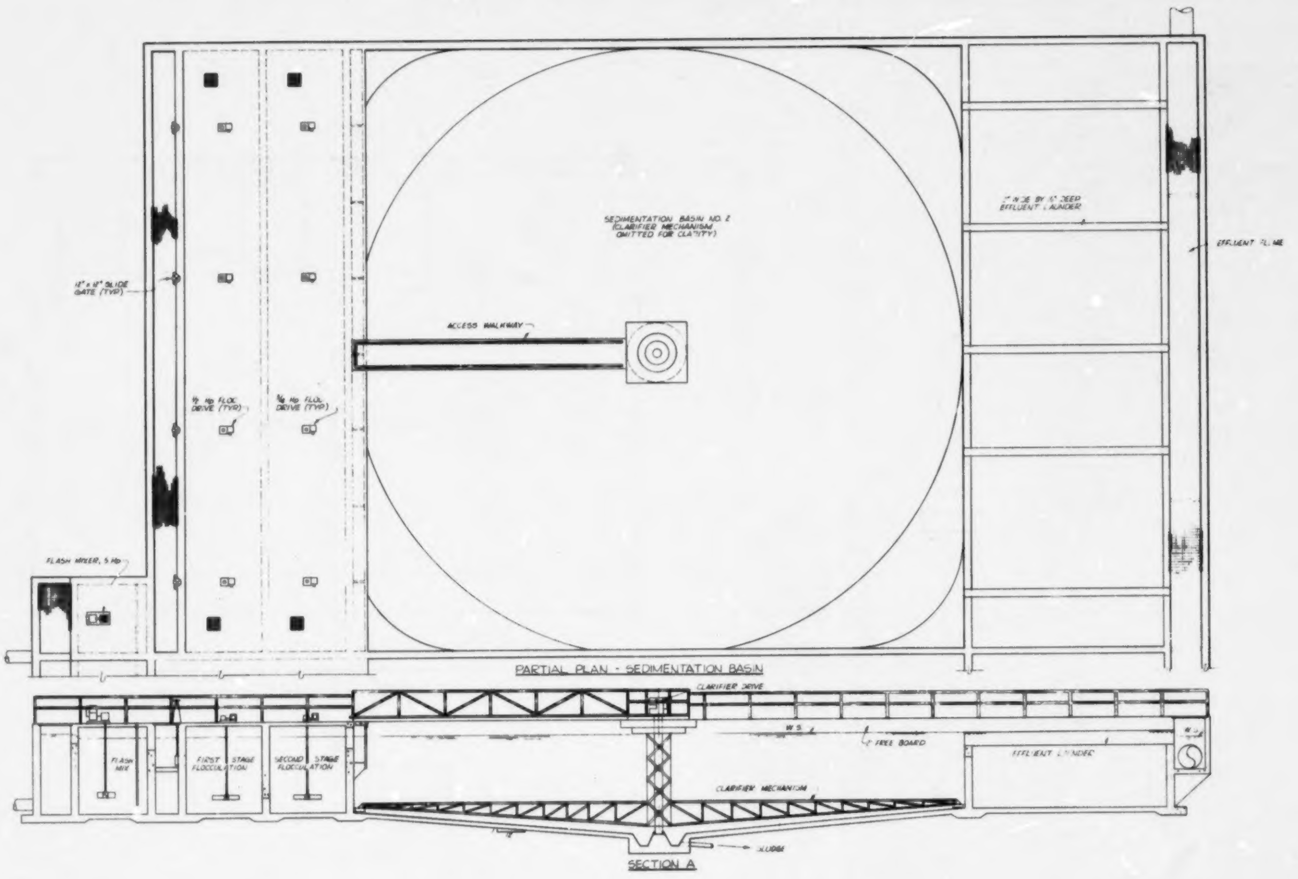

SEDIMENTATION BASIN NO. 2
(CLARIFIER MECHANISM
OMITTED FOR CLARITY)
12" x 12" SLIDE GATE (TYP)
ACCESS WALKWAY
½ Hp FLOC DRIVE (TYP)
⅛ Hp FLOC DRIVE (TYP)
FLASH MIXER, 5 Hp
EFFLUENT LAUNDER
EFFLUENT FLUME
PARTIAL PLAN - SEDIMENTATION BASIN
CLARIFIER DRIVE
W.S.
FREE BOARD
EFFLUENT LAUNDER
FLASH MIX
FIRST STAGE FLOCCULATION
SECOND STAGE FLOCCULATION
CLARIFIER MECHANISM
SLUDGE
SECTION A

Figure 221. Partial plan for sedimentation basin for 10-mgd water treatment plant.

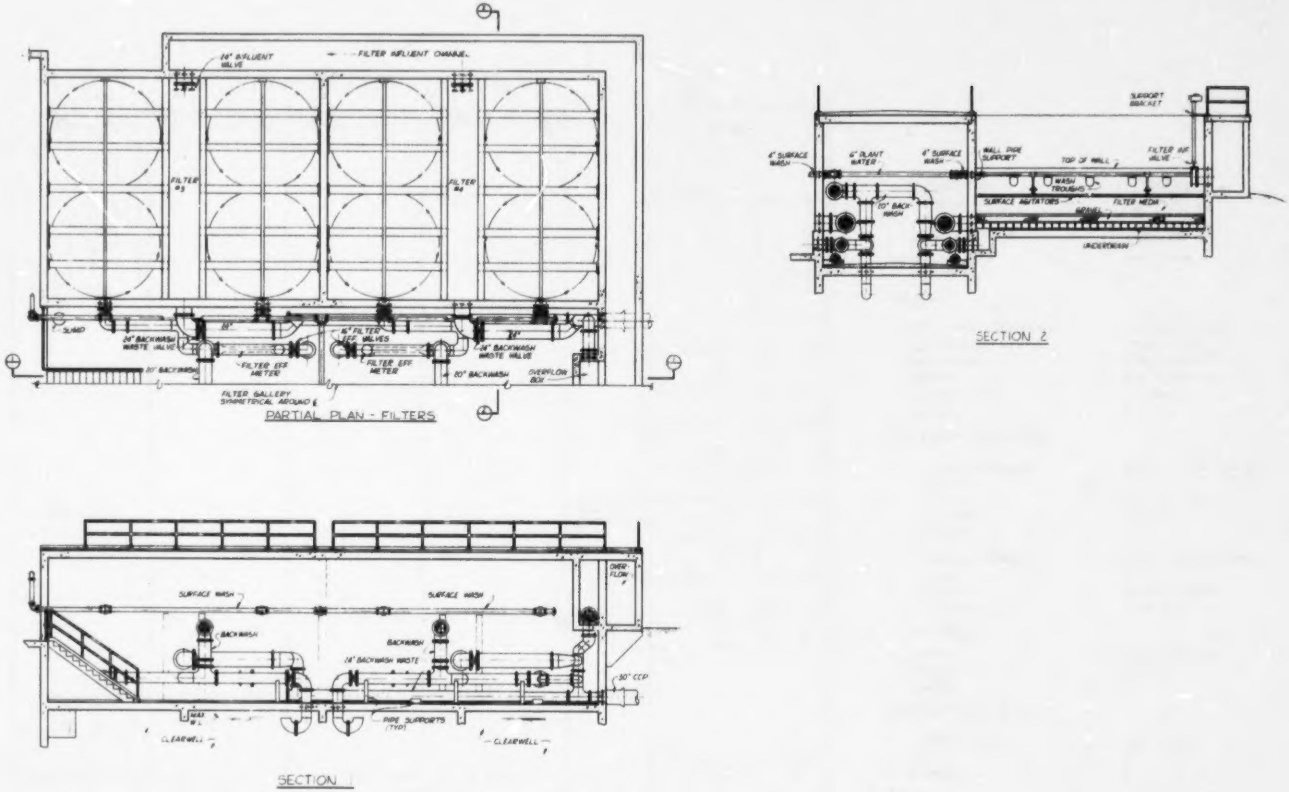
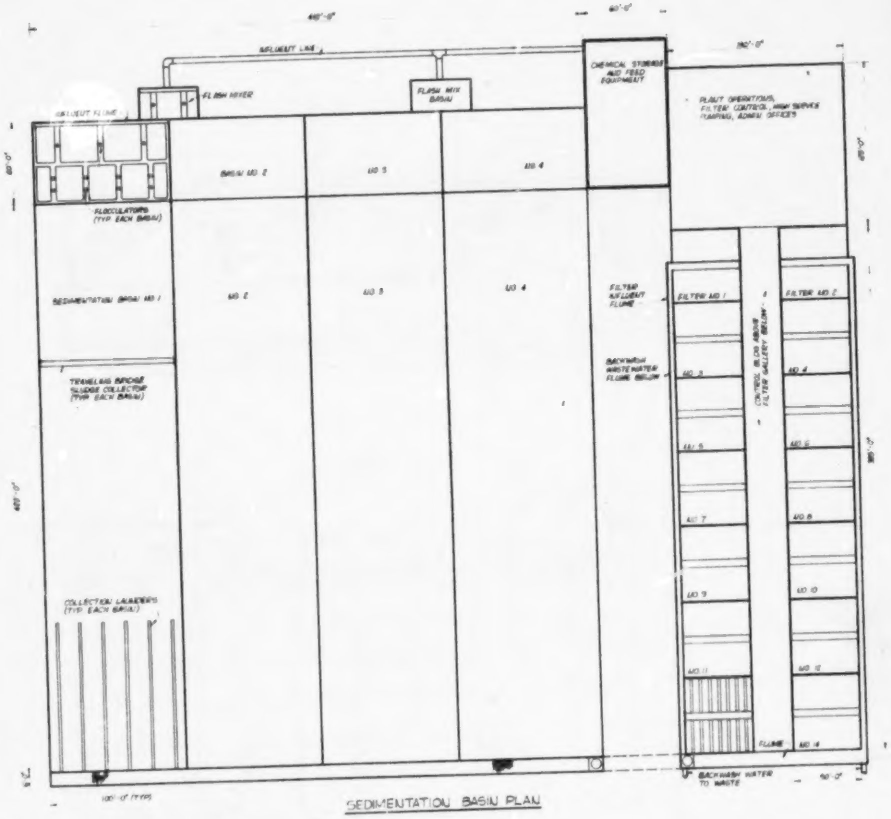

24" INFLUENT VALVE
FILTER INFLUENT CHANNEL
FILTER #3
FILTER #4
SUMP
24" BACKWASH WASTE VALVE
18"
16" FILTER EFF VALVES
24" BACKWASH WASTE VALVE
20" BACKWASH
FILTER EFF METER
FILTER EFF METER
20" BACKWASH
OVERFLOW BOX
FILTER GALLERY SYMMETRICAL AROUND ℄
PARTIAL PLAN - FILTERS
SUPPORT BRACKET
4" SURFACE WASH
6" PLANT WATER
4" SURFACE WASH
WALL PIPE SUPPORT
TOP OF WALL
FILTER INF VALVE
WASH TROUGHS
SURFACE AGITATORS
FILTER MEDIA
GRAVEL
20" BACKWASH
UNDERDRAIN
SECTION 2
SURFACE WASH
SURFACE WASH
OVERFLOW
BACKWASH
BACKWASH
18" BACKWASH WASTE
30" CCP
MAX W.L.
PIPE SUPPORTS (TYP)
CLEARWELL
CLEARWELL
SECTION 1

Figure 222. Filter layout for 10-mgd water treatment plant


INFLUENT LINE
FLASH MIXER
FLASH MIX BASIN
CHEMICAL STORAGE AND FEED EQUIPMENT
PLANT OPERATIONS, FILTER CONTROL, HIGH SERVICE PUMPING, ADMIN OFFICES
INFLUENT FLUME
FLOCCULATORS (TYP EACH BASIN)
BASIN NO. 2
NO. 3
NO. 4
SEDIMENTATION BASIN NO. 1
NO. 2
NO. 3
NO. 4
TRAVELING BRIDGE SLUDGE COLLECTOR (TYP EACH BASIN)
COLLECTION LAUNDERS (TYP EACH BASIN)
FILTER INFLUENT FLUME
BACKWASH WASTEWATER FLUME BELOW
CONTROL BLDG ABOVE FILTER GALLERY BELOW
FILTER NO. 1
FILTER NO. 2
NO. 3
NO. 4
NO. 5
NO. 6
NO. 7
NO. 8
NO. 9
NO. 10
NO. 11
NO. 12
FLUME
NO. 14
BACKWASH WATER TO WASTE
100'-0" (TYP)
90'-0"
60'-0"
SEDIMENTATION BASIN PLAN

DESIGN CRITERIA	
PLANT FLOW:	100
FLASH MIX BASINS:	
Number	2
Detention	1 min
Volume	35,000 gal each
Mixers:	
Number	4
Hp	50
Velocity gradient	700 sec^{-1}
FLOCCULATION BASINS:	
Number	4
Detention	30 min
Volume	525,000 gal each
1st stage:	
Number	3/basin
Type	Vertical turbine
Hp	5
Velocity gradient	75 sec^{-1} max (variable)
2nd stage:	
Number	8/basin
Type	Vertical turbine
Hp	½
Velocity gradient	25 sec^{-1} max (variable)
SEDIMENTATION BASINS:	
Number	4
Overflow rate	600 gpd/ft^2
Volume	4.37 mil gal each
Weir length	1,000 ft/basin
Weir overflow rate	25,000 gpd/ft^2
Type sludge collector	Travelling bridge
FILTERS:	
Number	14
Type	Rapid sand
Filter rate	2 gpm/ft^2
Backwash rate	
Nominal	15 gpm/ft^2
Maximum	18 gpm/ft^2

Figure 223. Facility layout for 100-mgd water treatment plant.

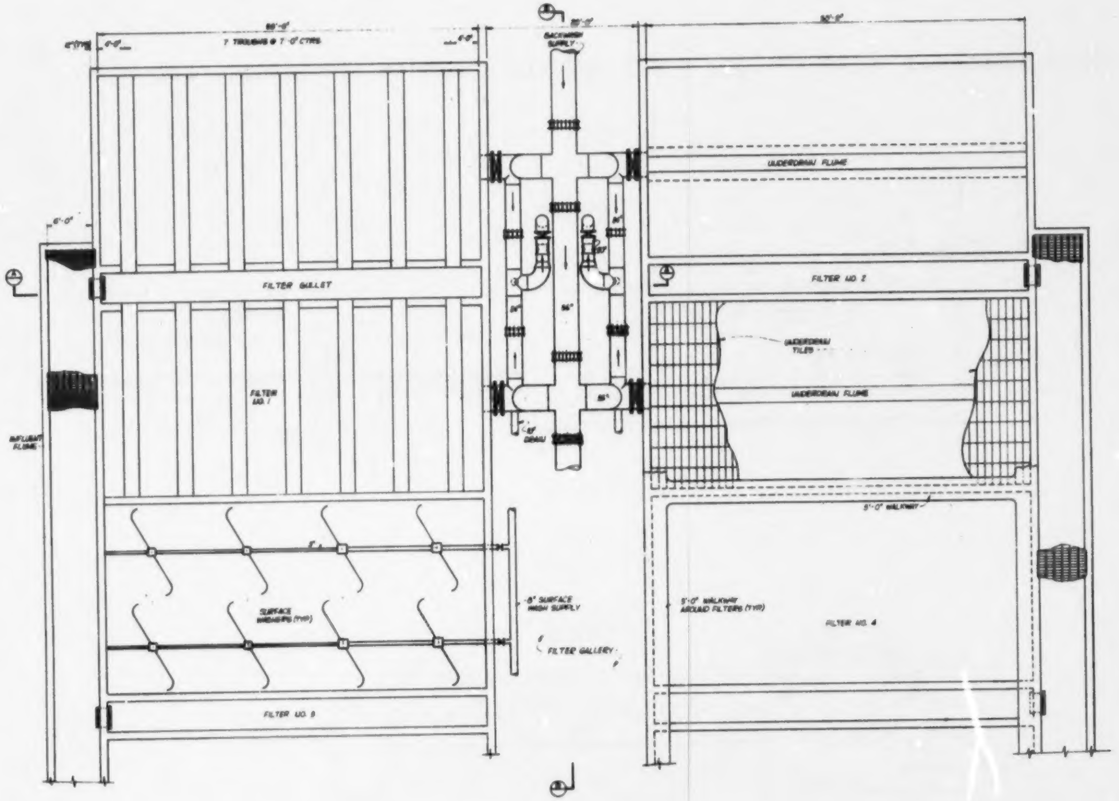

7 TROUGHS @ 7'-0" CTRS
BACKWASH SUPPLY
6'-0"
FILTER GULLET
FILTER NO. 1
INFLUENT FLUME
36"
24"
DRAIN
SURFACE WASHERS (TYP)
8" SURFACE WASH SUPPLY
℄ FILTER GALLERY
FILTER NO. 3
UNDERDRAIN FLUME
FILTER NO. 2
UNDERDRAIN TILES
UNDERDRAIN FLUME
5'-0" WALKWAY
5'-0" WALKWAY AROUND FILTERS (TYP)
FILTER NO. 4
PARTIAL PLAN - FILTERS

Figure 224. Partial plan for filters for 100-mgd water treatment plant.

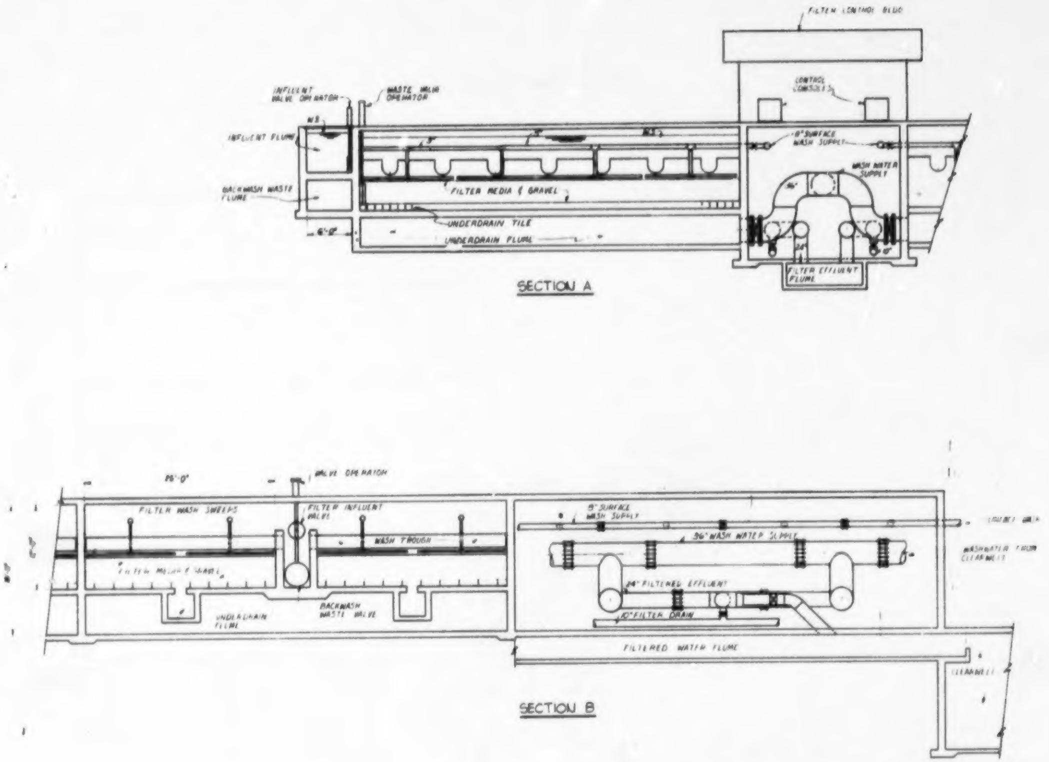

FILTER CONTROL BLDG
CONTROL CONSOLES
INFLUENT VALVE OPERATOR
WASTE VALVE OPERATOR
INFLUENT FLUME
BACKWASH WASTE FLUME
FILTER MEDIA & GRAVEL
UNDERDRAIN TILE
UNDERDRAIN FLUME
6'-0"
8" SURFACE WASH SUPPLY
WASH WATER SUPPLY
36"
24"
10"
FILTER EFFLUENT FLUME
SECTION A
26'-0"
VALVE OPERATOR
FILTER WASH SWEEPS
FILTER INFLUENT VALVE
WASH TROUGH
FILTER MEDIA & GRAVEL
UNDERDRAIN FLUME
BACKWASH WASTE VALVE
8" SURFACE WASH SUPPLY
36" WASH WATER SUPPLY
WASHWATER FROM CLEARWELL
24" FILTERED EFFLUENT
10" FILTER DRAIN
FILTERED WATER FLUME
CLEARWELL
SECTION B

Figure 225. Sectional views of filters for a 100-mgd water treatment plant.

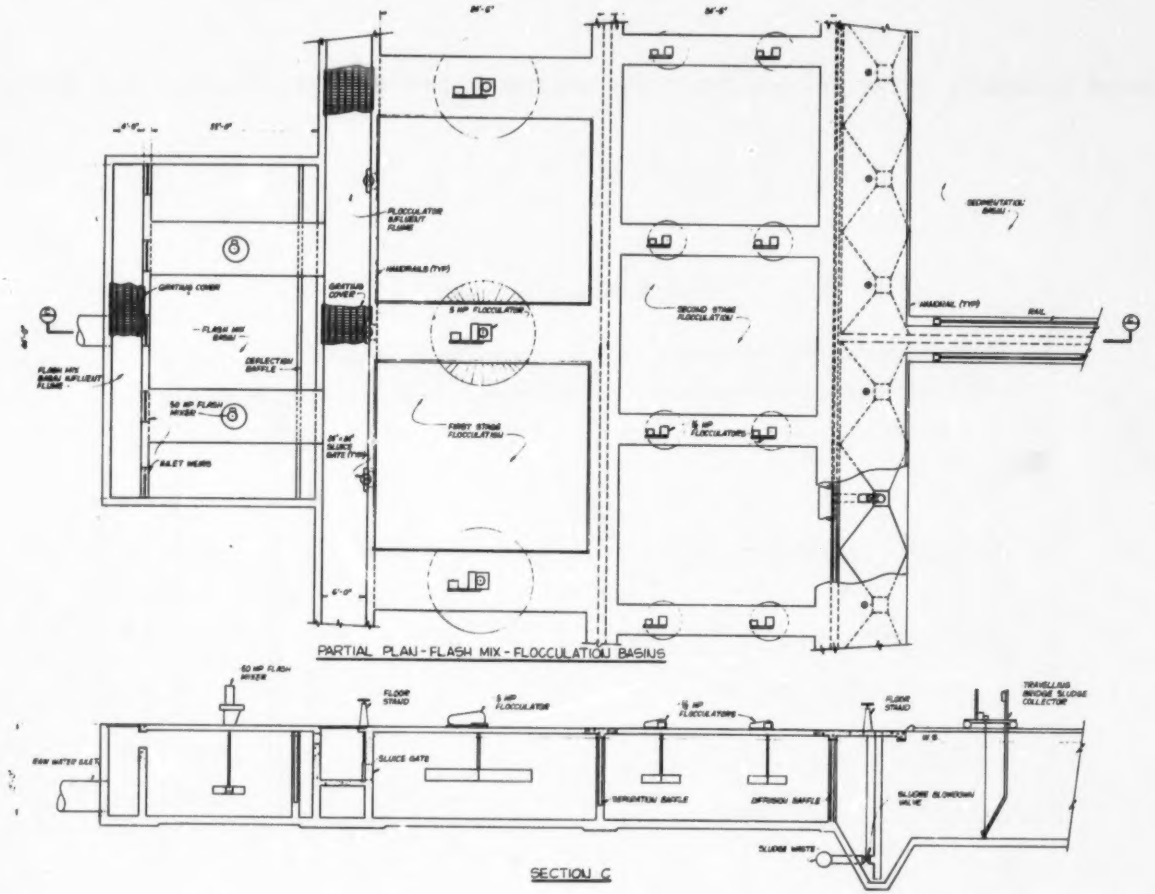

PARTIAL PLAN - FLASH MIX - FLOCCULATION BASINS
SECTION C
GRATING COVER
FLASH MIX BASIN
DEFLECTION BAFFLE
FLASH MIX BASIN INFLUENT FLUME
50 HP FLASH MIXER
INLET WEIRS
FLOCCULATOR INFLUENT FLUME
HANDRAILS (TYP)
5 HP FLOCCULATOR
FIRST STAGE FLOCCULATION
SLUICE GATE (TYP)
6'-0"
SECOND STAGE FLOCCULATION
½ HP FLOCCULATORS
SEDIMENTATION BASIN
HANDRAIL (TYP)
RAIL
60 HP FLASH MIXER
FLOOR STAND
5 HP FLOCCULATOR
½ HP FLOCCULATORS
FLOOR STAND
TRAVELLING BRIDGE SLUDGE COLLECTOR
RAW WATER INLET
SLUICE GATE
SEPARATION BAFFLE
DIFFUSION BAFFLE
SLUDGE BLOWDOWN VALVE
SLUDGE WASTE
W.S.

Figure 226. Partial plan for flash mix and flocculation basins for 100-mgd water treatment plant.

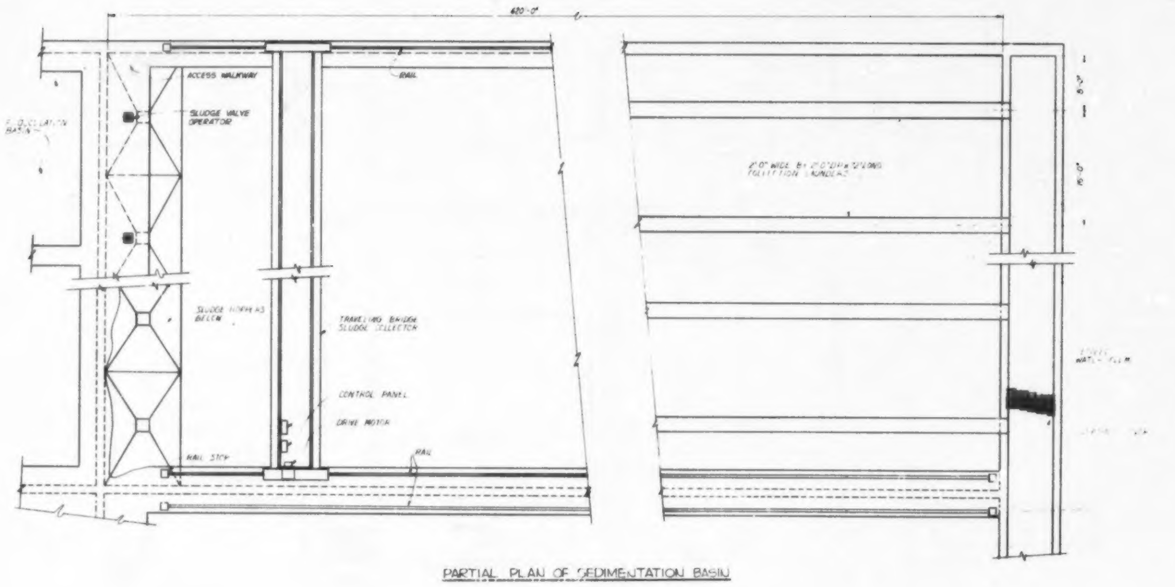

420'-0"
ACCESS WALKWAY
RAIL
SLUDGE VALVE OPERATOR
FLOCCULATION BASIN
SLUDGE HOPPERS BELOW
TRAVELING BRIDGE SLUDGE COLLECTOR
CONTROL PANEL
DRIVE MOTOR
RAIL STOP
RAIL
2'-0" WIDE BY 2'-0" DP x 72'LONG COLLECTION LAUNDERS
8'-0"
15'-0"
WATER FLOW
PARTIAL PLAN OF SEDIMENTATION BASIN

Figure 227. Partial plan of sedimentation basin for 100-mgd water treatment plant.

SECTION 5

EXAMPLE CALCULATION FOR A 40-MGD CONVENTIONAL TREATMENT PLANT

This example demonstrates the use of the curves included in Volume 2 to develop the cost of a 40-mgd conventional treatment plant, including sludge handling facilities. In this example, the plant design capacity is 40 mgd, but the facility is only operating at 70 percent of capacity, or 28 mgd.

The design criteria and operating conditions for the complete facility are shown in Table 185. As shown, the complete facility consists of all unit processes necessary for a complete and operating plant. The unit processes are design criteria, which are presented in Table 185, represent a hypothetical situation and should not be considered to be applicable to all treatment plants of this general capacity.

The total of the construction costs for the individual unit processes shown in Table 185 yield a subtotal cost that is the basis for a number of special costs more appropriately related to the subtotal of construction cost than to the construction cost of each individual unit process. These special costs include: (1) special sitework, landscaping, roads, and interface piping between processes, (2) special subsurface consideration, and (3) standby power. The special costs will vary widely, depending on the site, the design engineer's preference, and regulatory agency requirements. Addition of these special costs to the aggregate cost of the unit processes gives the total construction cost.

To arrive at the total capital cost, the following costs must be added to the total construction cost: (1) general contractor's overhead and profit, (2) engineering, (3) land, (4) legal, fiscal and administrative, and (5) interest during construction. Curves for these costs (except for engineering and land) are presented in Figures 228 to 232. A curve for engineering cost is not included, as the cost varies widely, depending on the need for preliminary studies, time delays, size and complexity of the project, and any construction-related inspection and engineering design activities.

Table 186 presents a calculation of total annual cost and cost per 1,000 gal treated. This calculation involves a number of variables such as amortization rate and period, labor rate (including fringes and benefits), electrical rates, and natural gas rates. The variables used in Table 186 are representative of U.S. averages, but they may vary significantly among geographical areas.

Table 185

Design Criteria and Cost Calculation for a 40 mgd Conventional Treatment Plant

System and Design Criteria	Figure Numbers*	Design Parameter	Construction Cost	Operating Parameter	Energy (kw-hr/yr)	Diesel Fuel (gal/yr)	Maintenance Material-($/yr)	Labor (hr/yr)
Alum Feed System - 40 mg/l	16, 19, 20	556 lb/hr	$ 71,440	350 lb/hr	46,260	0	100	65
Sodium Hydroxide Feed System - 15 mg/l	33, 34, 35	5000 lb/day	47,300	3300 lb/day	46,860	0	250	150
Polymer Feed System - 0.2 mg/l	21, 22, 23	67 lb/day	22,400	45 lb/day	26,280	0	300	207
Rapid Mix - 45 sec., G=600	50, 51, 52	2785 ft^3	44,210	2785 ft^3	284,180	0	60	499
Flocculation - 35 min., G=50	53, 55, 56	130,000 ft^3	447,070	130,000 ft^3	154,370	0	4,770	394
Rectangular Clarifiers - 1,000 gpd/ft^2	60, 61, 62	40,000 ft^3	2,247,330	40,000 ft^3	70,560	0	10,050	4,344
Gravity Filtration - 5 gpm/ft^2	67, 68, 69	5560 ft^2	1,747,730	5560 ft^2	978,200	0	12, 170	4,464
Filter Media - Mixed Media	70	5560 ft^2	148,200	-	0	0	0	0
Surface Wash	74, 75, 76	5560 ft^2	160,850	5560 ft^2	76,960	0	400	310
Backwash Pumping - 18 gpm/ft^2	71, 72, 73	10,010 gpm	122,530	5560 ft^2	132,840	0	3,170	294
Wash Water Surge Basin	80	200,000 gal	357,600	-	0	0	0	0
Chlorine Feed System - 2 mg/l	1, 2, 3	670 lb/day	68,980	450 lb/day	79,800	0	2,520	747
Clearwell Storage - Below Ground	207	2,500,000 gal	912,030	-	0	0	0	0
Finished Water Pumping	204, 205, 206	55 mgd	415,030	28 mgd	4,689,640	0	4,200	1,107
Gravity Thickener	166, 167, 168	850 ft^2	73,520	850 ft^2	4,140	0	230	145
Basket Centrifuge	185, 186, 187	115,000 gpd	334,810	70,000 gpd	476,760	0	3,000	8,300
Dewatered Sludge Hauling - 20 miles	196, 199, 200	20,000 yd^3/yr	81,510	12,000 yd^3/yr	0	4,820	5,250	914
Administrative, Laboratory & Maintenance Building	214, 215, 216	40 mgd	216,200	40 mgd	493,660	0	9,430	8,596
Subtotal	--	--	7,518,740	--	7,560,510	4,820	55,900	30,534
Sitework, Interface Piping, Roads, @ 5%	--	--	375,940	--	--	--	--	--
Subsurface Considerations	--	--	0	--	--	--	--	--
Standby Power	--	--	0	--	--	--	--	--
Total Construction Cost	--	--	7,894,680	--	--	--	--	--
General Contractor's Overhead and Profit	--	--	789,470	--	--	--	--	--
Subtotal	--	--	8,684,150	--	--	--	--	--
Engineering @ 10%	--	--	868,420	--	--	--	--	--
Subtotal	--	--	9,552,570	--	--	--	--	--
Land, 13 acres @ $26,000/acre	--	--	26,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	--	67,030	--	--	--	--	--
Interest during Construction - 7%	--	--	688,790	--	--	--	--	--
Total Capital Cost	--	--	$10,334,390	--	--	--	--	--

***Note - Figure numbers refer to Volume 2 of this report.**

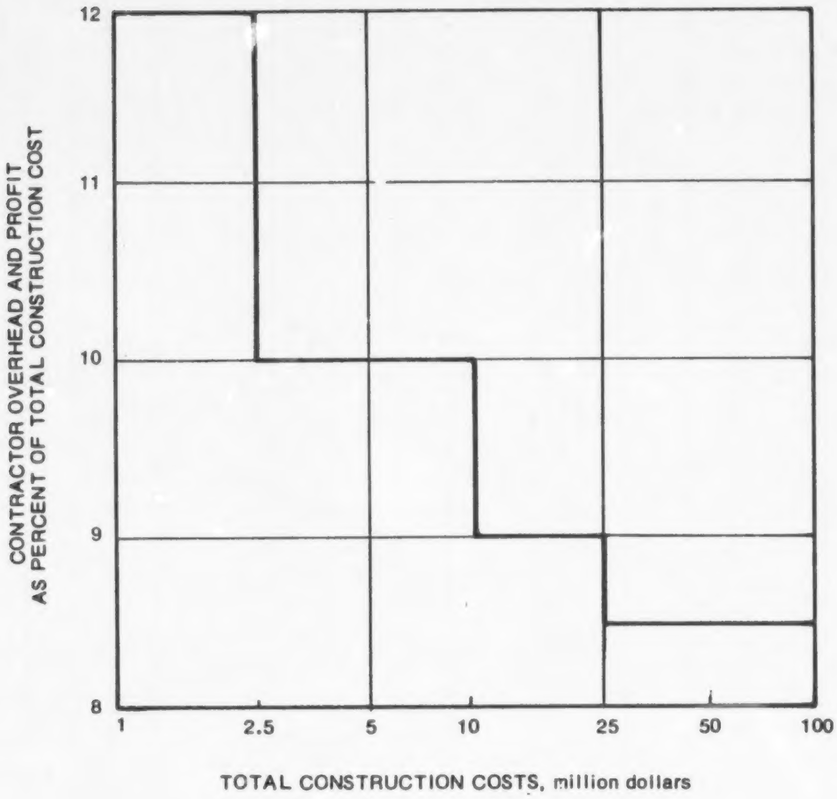


Figure 228. General contractor's overhead and fee percentage versus total construction cost.

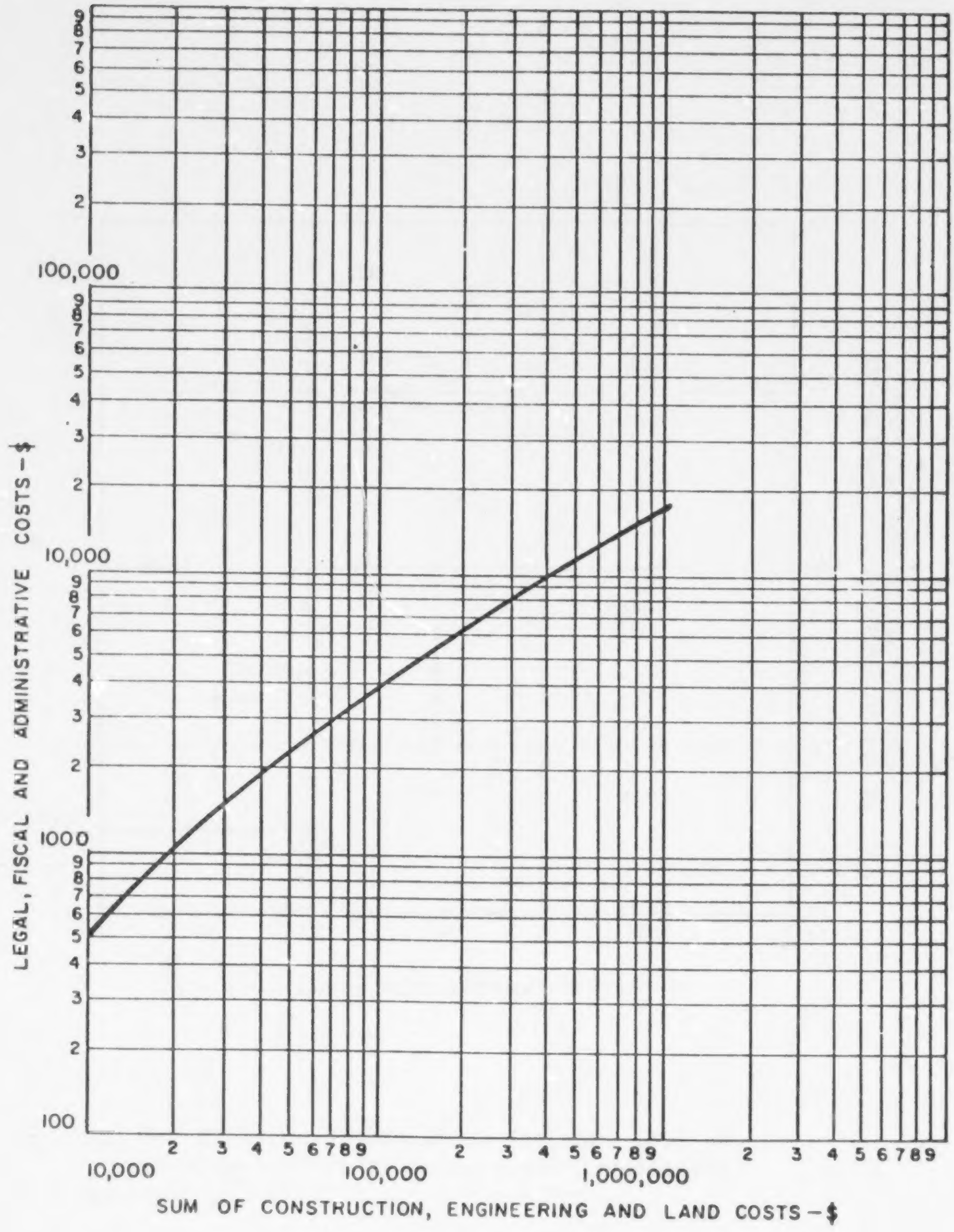


Figure 229. Legal, fiscal and administrative costs for projects less than $1 million.

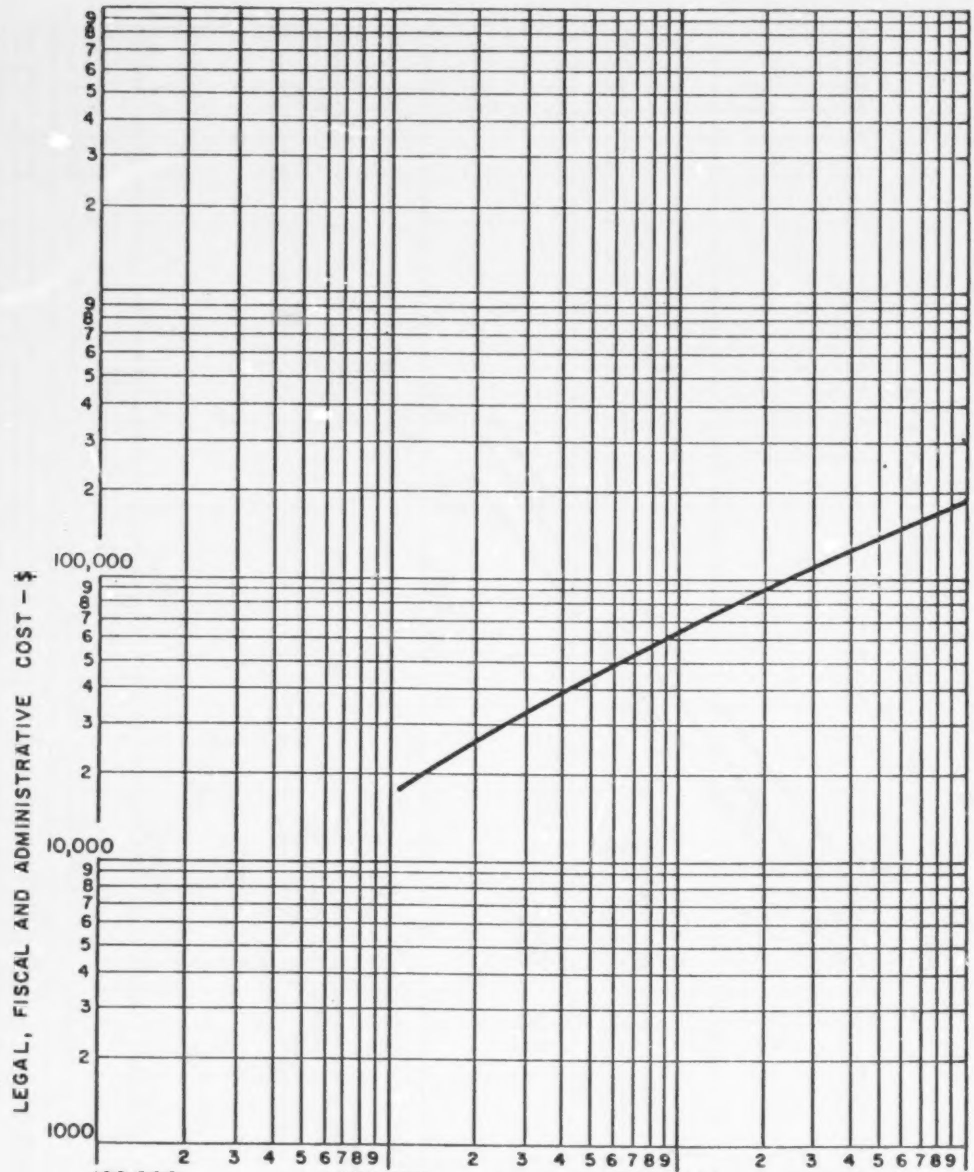


Figure 230. Legal, fiscal and administrative costs for projects greater than $1 million.

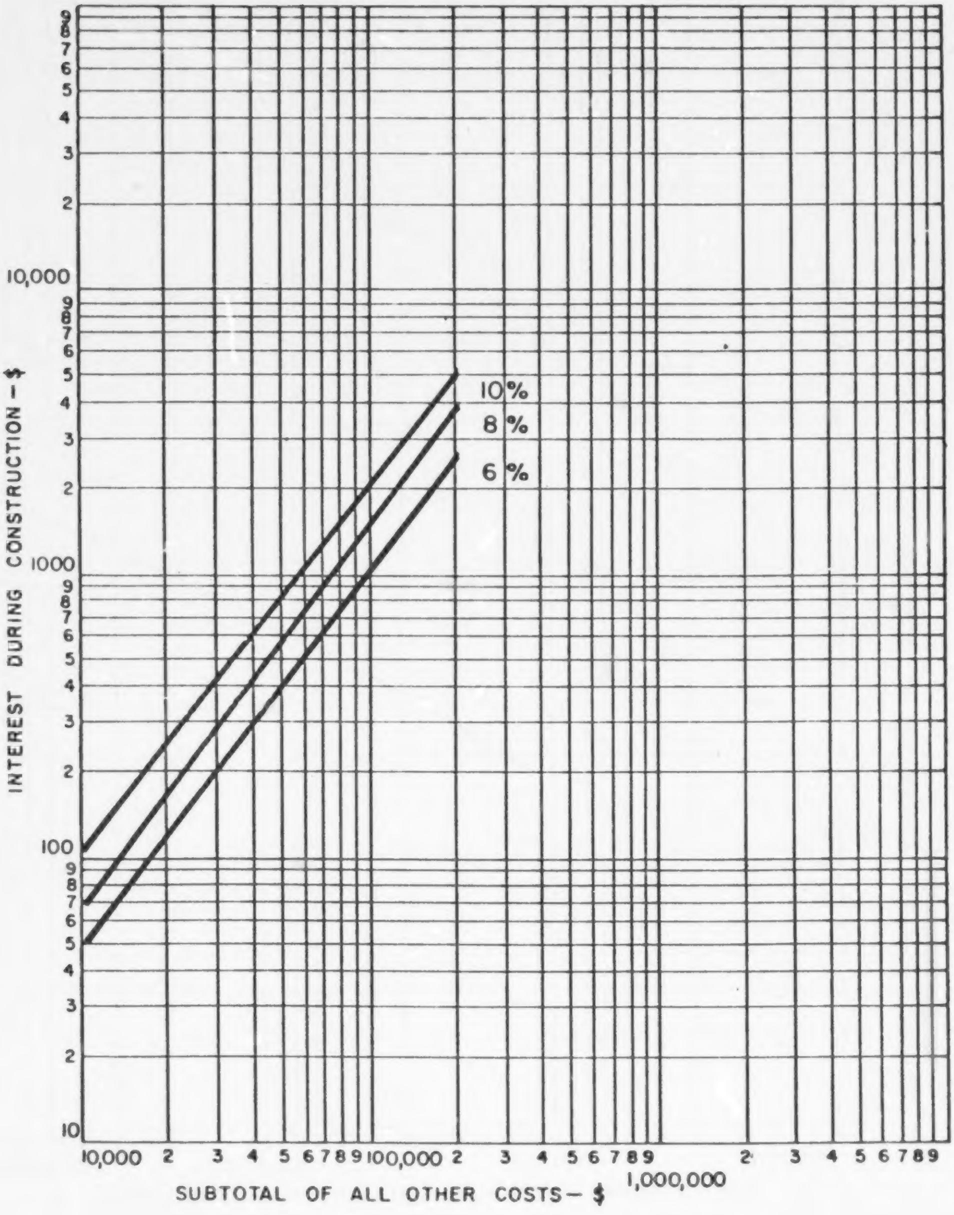


Figure 231. Interest during construction for projects less than $200,000.

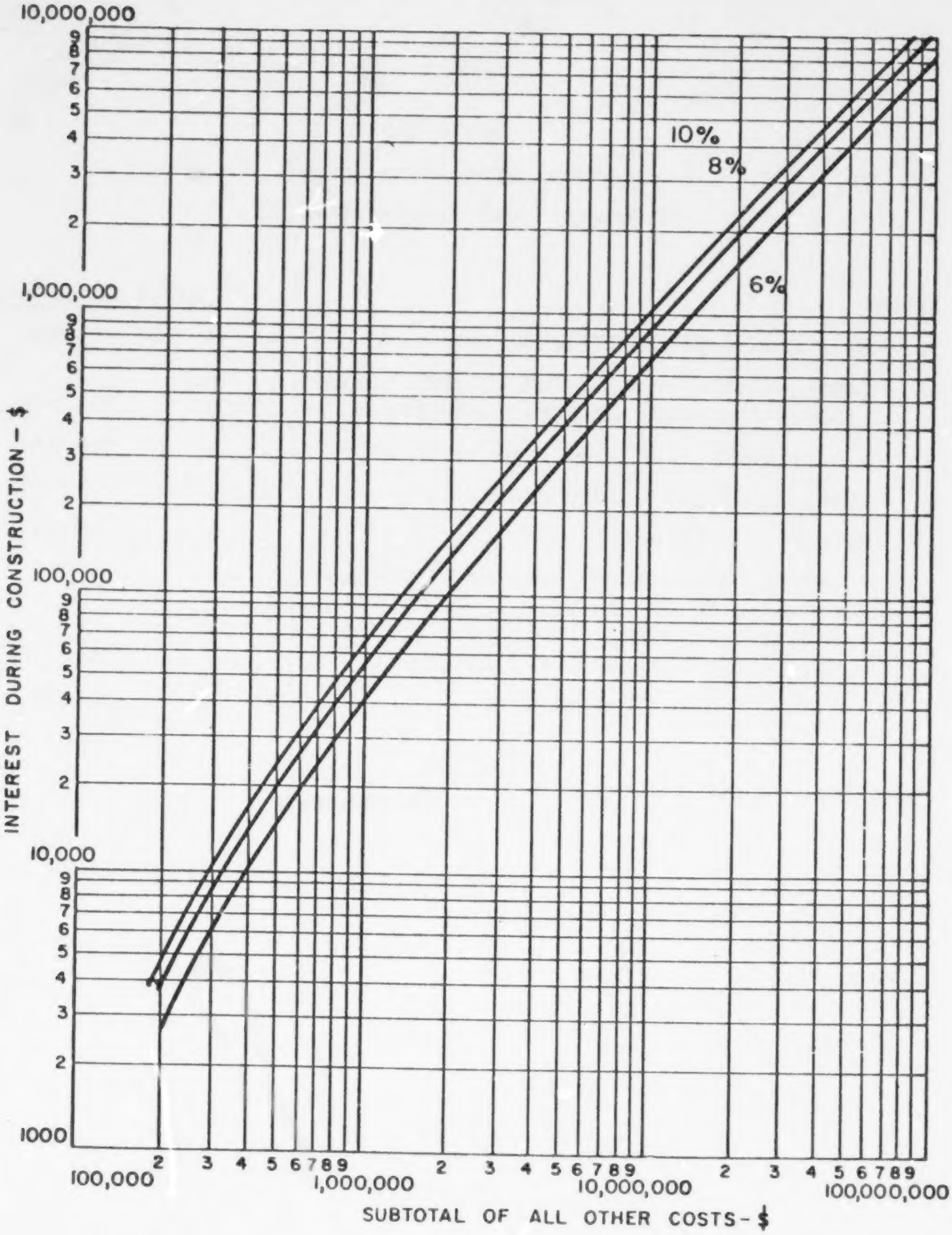


Figure 232. Interest during construction for projects greater than $200,000.

Table 186
Annual Cost for a 40 mgd
Conventional Treatment Plant

Item:	Total Costs/year
Amortized Capital @ 7%, 20 years	$ 975,460
Labor, 30,534 hr @ $10/hr, (Total labor Costs Including Fringes & Benefits)	305,340
Electricity, 7,560,510 kw-hr @ $0.03	226,820
Fuel, 4,820 gal @ $0.65/gal.	3,130
Maintenance Material	55,900
Chemical, Alum, 1,533 tons/yr @ $70/ton; Polymer, 16,425 lb/yr @ $2/lb Sodium Hydroxide, 602 tons/yr @ $200/ton; Chlorine, 82 tons/yr @ $300/ton	285,250
Total Annual Cost	$1,851,900

$$\text{*Cents per 1,000 gal treated} = \frac{\$1{,}851{,}900\ (100)}{28{,}000\ (365)}$$

$$= 18.12¢/1{,}000 \text{ gal treated}$$

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10. Producer Prices and Price Indexes, Data for October, 1978. Bureau of Labor Statistics, U.S. Department of Labor.

11. Hudson, H.E., High Quality Water Production and Viral Disease. Waterworks Assoc., October 1962, p. 1265